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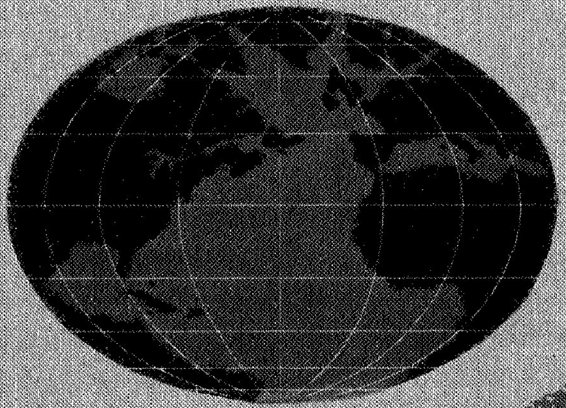

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Grumman Aircraft Engineering Corp., Bethpage, N.Y.

Grumman Project 226A

PRELIMINARY STUDY OF CAPSULE RECOVERY FOR THE FIRST SERIES OF PROJECT MERCURY ORBITAL FLIGHTS *

for the [6]

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SPACE TASK GROUP

(NASA contract NAS 5-71) (NASA CR- ;

report (PDR 226A-2)

JULY 1959 234p refs

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INTRODUCTION

This report contains the results of a preliminary study of the search and recovery operations required for the safe and expeditious return of the Mercury Recovery Capsule in the first series of orbital flights. It is submitted in accordance with the terms of the National Aeronautics and Space Administration Contract NAS 5-71 dated 8 May 1959. The study is concerned primarily with the high-probability impact areas in the Atlantic Ocean. Emphasis is placed on safe recovery within reasonable time at least cost.

A preliminary study of this nature is not able to provide final answers to all of the problems; the report instead constitutes a "first look" at the overall operation. Much of the report is therefore devoted to basic data, the building blocks from which recovery systems can be assembled and evaluated. These include the performance characteristics, reliability, and cost of the vehicles and equipment which may be used, and their compatibility with one another, with the capsule, and with the expected environment. The availability of vehicles and equipment has also been considered, although it is appreciated that this may change from week to week where the forces are drawn from the military services. Data are generally presented in a form which will permit the consideration of alternative vehicles, equipments, and systems, and their evaluation from the standpoint of effectiveness and cost. While the equipment considered is generally expected to be operational throughout 1960, consideration is also given to more advanced schemes which might effect reductions in recovery time, cost, or dependence upon the military forces.

It is hoped that this report will be of assistance to those in the NASA and the Department of Defense responsible for planning the recovery operation.

SUMMARY AND CONCLUSIONS

The Grumman Aircraft Engineering Corporation has made a preliminary study of the factors involved in the search and recovery operations associated with the return of the Mercury Satellite Capsule after the initiation of re-entry from one of its first, 3-orbit flights.

Currently-conceived, high-probability landing areas in the Atlantic Ocean are furnished by the NASA (Figure 46, page 156). A maximum recovery time is assumed and several aircraft and ship deployments are derived to furnish the following four recovery services for each area:

1) Detection of the capsule during descent before impact.
2) Search after impact.
3) Retrieval of the capsule from the water.
4) Delivery of the astronaut to astromedical representatives.

A local area detection of the capsule during descent results in almost certain success in search and retrieval. Recovery system effectiveness is therefore considered to be the same as the probability of finding the capsule with sufficient time remaining for the arrival of the retrieve vehicle, for the execution of the retrieve operation and for delivery of the capsule to an astromedical team within the assumed access time. Specific results show that a safe recovery can be achieved within a short time after the capsule lands, with a reasonable number of existing vehicles, regardless of the degree of assistance from the capsule location aids.

Three different recovery vehicle complexes are developed and analyzed. For each of them the retrieve vehicles are able to reach and retrieve the capsule from any point within the high probability landing areas and deliver it to astromedical representatives within the assumed recovery or access time. On the other hand, the search and detection vehicle array differs slightly for each of the three cases, depending upon the amount of local detection desired. For all three cases, however, both retrieve and detection coverage must be met with the minimum number of minimum cost vehicles which will be in operation and available in 1960.

Interest centers upon the differences among the three examples. In example I, the preferred system complex, detection vehicles are placed close enough to one another to provide active radar detection coverage, over the complete high-probability area, down to altitudes of approximately 8,000 feet in order to include the region of chaff deployment. The total number of vehicles required for active participation is 22: 9 fixed-wing aircraft used only for initial detection and search, 3 helicopters for picking the capsule out of the water, and 4 airships and 6 surface ships which serve in both detection and retrieval capacities.

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TABLE 1

SUMMARY: RECOMMENDED MINIMUM VEHICLE DEPLOYMENT

Detection system provides complete coverage for detection of chaff at 8000 ft. using aircraft, ships, and land stations

High Probability Landing Areas					Vehicle Deployment (22 Vehicles, Total)		Probability of Recovery Within Assumed Max. Access Time		
Area No.	Purpose of Area	Dimensions N. Mi.	General Location	Assumed Max. Access Time - hr.	Detection and Search	Detection and Retrieve	All Capsule Aids Working	Chaff Only	No Aids
1	Boost Abort	100 x 300	East of Cape Canaveral	3	1: S2F[1]	1: HR2S[2] +2: DD	.99	.99	.96
2	Sustainer Abort	40 x 1600	East of Area #1 to Mid-Atlantic	6	3: SA-16 +2: P5M	1: HUS[2] +2: DD +2: ZP	.99	.99	.94
3	Sustainer Abort	40 x 200	East of Area #2 along Launch Track	6	1:SA-16[1]	1: DD	.99	.99	.94
4	Sustainer Abort	40 x 200	East of Area #3 along Launch Track	6		1: DD	.99	.99	.94
5	Injection Abort	40 x 200	South of Canary Islands along Launch Track	3	1: S2F[1]	1:HR2S[2]	.99	.99	.96
6	Orbit #1 Landing	50 x 210	East of Bermuda where Orbit #1 crosses Launch Track	3	1:SA-16[3] +1:ZP[3]	1: ZP[3]	.99	.99	.96
7	Orbit #2 Landing	50 x 210	East of Area #1, where Orbit #2 crosses Launch Track	3	1:SA-16[3] +1:ZP[3]	1: DD[3] +1: ZP[3]	.99	.99	.67[4]
8	Planned Orbit #3 Landing	120 x 400	North of Hispaniola & Puerto Rico along 3rd Orbit Track	3	1:S2F[1]	2: ZP	.99	.99	.96

Notes: 1. Search only, detection by ships or land stations.
2. Retrieve only, detection by land stations.
3. Areas 6 and 7 covered by vehicles assigned initially to Area 2, redeployed as necessary.
4. Can be increased to .99 by assuming 3.5 instead of the 3.0 hour maximum access time.

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PRELIMINARY RECOVERY STUDY

If the capsule is not detected locally before impact, and none of its many location aids function, this preferred vehicle complex, nevertheless, results in a 92% probability of recovery within 3 hours after impact in all areas except the launch abort sections in mid-Atlantic for which a 6 hour maximum has been allowed. If chaff is deployed with the main parachute, as planned, at 10,000 feet altitude, the recovery probability was found to increase to 99%. If the many additional location aids function properly, redundency is added to the system, the search time is reduced, and the recovery probability rises above 99%. It is apparent that chaff is one of the most effective of the capsule location aids. Because the vehicles are spaced to cover long and rather narrow tracks, their capability extends out some distance on either side, and they can actually cover a considerably greater area than that to which they are assigned.

The operational cost of the recovery, assuming no delays in firing, will be about $700,000 taking into account fuel, oil, other consumables, and direct military personnel pay and allowances. This amount would be doubled in the event of 8 or 9 daily postponements.

The criterion for the second example (II) is that detection vehicles must be spaced close enough to one another to provide complete line-of-sight coverage of the ocean surface (instead of only down to 8000 feet). This is to allow complete impact area monitoring for radio direction-finding signals. To get range information, however, it will probably be necessary to modify the capsule S-band beacon to allow it to respond to simple inquiry from aircraft with compatible radar, such as the WF-2, AD-5W, P2V and WV-2. With this modification to the capsule equipment, the three additional aircraft required to satisfy this criteria are enough to eliminate the need for any capsule detection capability in the surface vessels.

Search time is reduced slightly with this vehicle arrangement, but the probability of recovery and the recovery time remain virtually unchanged. Because of the greater number of aircraft required, cost of the operation will increase over that in example I, but the increase is expected to be less than 10%.

In the third example (III), on the other hand, the number of vehicles is reduced. The detection aircraft are spaced farther apart to reduce the number required and thus the cost of the operation. The requirement for a local area detection before impact is put aside, and the search aircraft are spaced as far apart as possible consistent with their ability to locate the capsule soon enough to direct the retrieve vehicle to the scene to complete the recovery within the assumed access time. Because of the particular geometry and geography of the impact areas under study, only three vehicles can be eliminated. One aircraft on the ground at Bermuda replaces four aircraft on station over the launch-abort area in example I. Local detection before impact is impossible over much of this area and it is assumed, where this is the situation, that an uncertainty area of 60 miles in diameter will be available from shore-based tracking and impact prediction data.

This third system has the least cost, but it is not necessarily the recommended system. There is slightly less chance of recovery within the assumed access time than in example I because of the longer search time required when there is

no local contact before impact (when no capsule location aids function). This results in a somewhat lower probability that the search aircraft's search equipment will be operating properly. But the main reason is that the increased space between detection vehicles may place too much dependence upon land-based tracking for impact prediction without the redundancy of local detection.

Because of the geometry of these particular high-probability impact areas and their proximity to several land bases, the cost reduction due to the greater spacing of detection vehicles is only a few percent when compared with the preferred system (I).

Except for shifting some aircraft in the launch abort area to cover orbit emergency landings, it is not possible to redeploy recovery vehicles from one area to another because of the short time available. Many of the vehicles do have the fuel capacity to redeploy, however, and if there should be a delay in locating the capsule, they could assist in extending the search.

Additional aircraft must be assigned in a back-up role to insure against costly launch delays or postponements caused by recovery vehicle availability problems. For example, with an average availability of 75%, 4 aircraft are required to maintain a 95% probability that 2 will be available.

The principal operational costs will be those incurred in staging the detection and retrieving forces and recycling them to their stations as required until the capsule has been successfully launched and recovered. These costs will be determined by the number of vehicles required and the operating costs of the vehicles selected. Inasmuch as low access time is a major requirement, the number of vehicles required is determined primarily by their speed. High speed vehicles are to be preferred, in general. Aircraft are the most economical where they are suitable: helicopters and airships for retrieval, and fixed-wing aircraft for search and detection. For minimum cost, the aircraft should be deployed at land bases and should be permitted to stand by on the ground during firing delays wherever possible. Large seaplanes capable of carrying the capsule and fixed-wing aircraft capable of aerial pickup from the water would provide the most economical recovery system if they were operationally proven.

Surface ships will be required for retrieval beyond the range capabilities of airships. The destroyer types (DD, DDE, DDR) appear to be the least expensive of the surface ships for all-around application. The use of an aircraft carrier cannot be justified on economic grounds because the geography and geometry of the high-probability areas limits the number of carrier-based aircraft which could be used to advantage from a single carrier. Smaller ships operating as helicopter bases, such as the LSD, are competitive with destroyers only if the particular conditions of area size and permissible access time are such that the helicopter may be utilized during most of the access time.

Crews of aircraft involved in ASW and ASR operations have developed techniques and skills which make them especially valuable for this recovery operation, and they should be used wherever it is practical. Navigational errors and capsule drift are found to have a negligible effect on recovery time. Existing Navy communications channels are adequate but care should be taken to "peak" the equipment which is to be used.

The best time for launch, from the standpoint of recovery operations, appears to be during the night in the summer months between June and September. The incandescence during re-entry and the high-intensity flashing light, which comes on after landing, can be detected at night from much greater distances than any of the "daytime-only" location aids. Radio reception is generally better than during the day so long as critical periods at sunset and sunrise are avoided. Weather is best during the summer months; winds, sea state and overcast are a minimum throughout all the high-probability landing areas with the one exception of the Canary Islands where strong winds are likely. Although search times for examples in this study are generally based on radar range with sea state of 2-3, recovery can be made in rougher seas but it may be more difficult and take more time.

There are a number of improvements that appear promising for future recovery systems. The greatest savings in recovery time, number of vehicles required and cost will result from the use of long range, high speed, fixed-wing aircraft which contain the combined capability of detection, search and retrieve vehicles. Nine, 300-knot aircraft on station at 30,000 feet altitude, for example, when equipped for beacon detection and for in-flight pick-up of the capsule from the water, by either the snatch or long-line techniques, could replace the 22 vehicle preferred system complex for the same 187,000 sq. nautical miles of high-probability landing area. Access time would be less than one hour as compared with a maximum of six hours, and operating cost, including staging considerations, would be less than 10% of cost for the presently recommended example (I). This figure does not include the cost of any special aircraft modification.

The snatch technique utilizes a hook or loop of line suspended below an aircraft to catch a loop or hook attached to the capsule as the aircraft flies over it. Weights only as high as 800 pounds have been retrieved to date with this system, however. The long-line technique applies a more gradual application of lift and utilizes a long line, with a hook on its end, suspended from a circling aircraft. With the proper weight and geometry, the hook will trail at the center of the circle. After it engages the capsule, the circling aircraft climbs and the capsule is lifted clear. Successful experiments with this pick-up method have also been limited to weights considerably less than the possible 2500 pounds for the capsule, and a test program would be required to check the feasibility of these systems before they could be used to effect savings in the Mercury capsule recovery operations.

Large seaplanes such as the JRM and R3Y, although of lower-speed and altitude capability, could provide additional back-up with their ability to land beside the capsule and their excellent existing hoist and stowage techniques.

Use of high-speed (80 knots) surface craft, such as hydrofoil boats, could result in a reduction of retrieval vehicles from the presently proposed 13 to 6 consistent with the assumed maximum access time for each area.

RECOMMENDATIONS

On the basis of this study, the following recommendations are made:

I. Recovery System for the Early Three-Orbit Missions: It is recommended that the high-probability impact areas be monitored with a complex of currently operated destroyer-type surface ships, fixed-wing aircraft, lighter-than-air ships, and land-based helicopters, plus the existing and projected land radar stations located in or near the several areas. Helicopters should be used for retrieval close to suitably-located land bases; airships, for detection and retrieval beyond helicopter range, within the limits of their operational suitability and availability; surface ships, for detection and retrieval in the more remote areas; and fixed wing aircraft, for detection, as required, and for search after impact.

II. Development of Vehicles and Recovery Techniques for Future Missions: It is recommended that further investigation and possible development be pursued with respect to high speed vehicles suitable for capsule retrieval and to the corresponding appropriate retrieval techniques, for replacement of the airships and destroyer-type surface ships recommended above. This should include evaluation of the capabilities of large seaplanes able to take the capsule aboard, evaluation of the use by fixed-wing aircraft of water-to-air snatch or "long line" lift techniques, and consideration of the application of hydrofoil boats or other high-speed surface ships at such time as they become available.

III. Operational Considerations: It is recommended

a. that the mission take place during the months of May through September for best weather conditions throughout most of the currently anticipated high-probability areas;

b. that launch be scheduled so that re-entry, impact, and the expected search period occur during darkness before daybreak, so that visual detection can be assisted by capsule incandescence during re-entry and by the capsule flashing light after impact;

c. that daylight visual aids, such as the dye marker, be accordingly delayed or prolonged if automatic, or be used only at the discretion of the astronaut; and

d. that critical periods of communication be avoided during sunrise and sunset, and that regular FOX broadcasts be made at short intervals for some period from before launch through recovery for monitoring by ship's radio watch to check equipment performance and best receiving frequency.

IV. Modifications to Capsule, its Equipment, and Recovery Vehicle Equipment: In order to facilitate recovery, it is recommended

a. that a floatable lift-line be deployed overboard at impact;

b. that a bail, loop, hook, or eye be made readily accessible on top of the capsule;

c. that the main parachute be made buoyant for visual aid after impact;

d. that a study be made of changes required to permit quick access to the capsule interior and to the occupant;

e. that capsule S-Band beacon interrogation requirements be changed at drogue chute deployment to become compatible with the AN/APS-20 radar, or if that is not possible and if battery capacity permits, that the beacon free-run during parachute descent;

f. that ships assigned to the recovery forces have the latest single side band communications equipment installed; and

g. that a check be made of the feasibility of adding to the capsule an X-Band beacon compatible with radar carried by most military aircraft.

The most useful single location aid is the chaff, and care should be given to assure proper operation of the dispensing mechanism.

V. Tests to Verify Conclusions and Recommendations of this Study: It is recommended that a flight-type capsule be floated in various sea states and dropped in various wind conditions to check pilot egress and techniques for gaining access to and removing him, effectiveness of the flotation bags, the weight of shipped water, effectiveness of visual aids when viewed from ships and aircraft, radar target of the capsule in the water, ranges at which direction-finding equipment and operators can detect and recognize the capsule, liklihood of the main parachute falling on top of the capsule, and the adverse effect on the electronic aids or pilot egress in such event.

VI. Supplementary and Complementary Studies: It is recommended

a. that the problem of recovery in low-probability areas of the world, especially along the three-orbit mission track, be subjected to further study in its own right; and

b. that a study be made of the effectiveness and cost of alternate ways of manning the recovery forces (regular armed forces, MATS, MSTS, private contractor, etc.).

I GENERAL RECOVERY CONSIDERATIONS

I. GENERAL RECOVERY CONSIDERATIONS

GENERAL

In this section, various aspects of the capsule recovery operation are considered without regard to the specific impact areas which must be monitored during the actual launch. By thus studying the general requirements for recovery of the capsule from any arbitrary area, solutions to some of the broad problems of the operation become evident and are applicable to the high-probability impact areas themselves. The next section of this report then analyzes the specific expected impact areas and the detailed recovery support required for each, utilizing the general solutions evolved in this section.

Although this section considers general recovery requirements, the nature of the planned Mercury operation limits the necessary scope of the hypothetical arbitrary impact area. The orbit path will be within $32\frac{1}{2}^{\circ}$ N and $32\frac{1}{2}^{\circ}$ S latitude, so only tropical and temperate climates need be considered. The intention of a water landing for the capsule has been specified, so little attention is given to land recovery, although some analysis is given where possible re-entry errors would allow an impact on land.

The objectives of Project Mercury demand that the capsule and occupant be secured as soon as possible after re-entry so that project astromedical personnel can examine and interrogate the capsule pilot while his experiences are fresh in mind. Furthermore, delay in recovery can result in physiological and psychological hazards to the pilot due to continued isolation, exposure, and tossing of the capsule. The highest possible order of reliability and probability of success is mandatory. On the other hand, the amount of recovery support must be consistent with practical limits of cost and availability of vehicles, equipment, and personnel.

The recovery force has three responsibilities. As the orbiting vehicle re-enters the atmosphere, it must be detected and tracked to the splash point. After impact, a search must be conducted to locate the capsule. Finally, the capsule and occupant must be recovered from the sea, and the occupant must be presented to the appropriate medical facilities and personnel with minimum delay. Satisfactory performance of each task depends upon successful completion of each previous task. Support to the recovery force must be given by other units of Project Mercury, especially land-based coordination and tracking facilities which must provide timely data on launch scheduling, success of orbit injection, nature of the orbit, time of retrorocket firing, and prediction of impact time and location.

Project Mercury is a high-priority program demanding the most expeditious solutions to the development of suitable hardware and techniques for the manned capsule orbit attempts. Only equipment which is presently available, or can be

quickly developed, may be considered for the initial recovery operations. Maximum effectiveness at minimum cost in dollars and diversion of effort by the Armed Services, which have the responsibility of providing the recovery support, should be sought. Retrieval of the capsule in an undamaged condition is desired so that proper inspection, recovery of records, and re-use of the capsule will be feasible. With these objectives in mind, this section investigates the relative capability, availability, and cost of equipment, effectiveness of various track, search, and retrieving techniques, and general coordination, communication, and other functional tasks required to meet the general requirements of recovery.

CAPSULE DESIGN AND OPERATION

The discussion of the capsule design and operation is divided among the following sections:

General Mission Description (with trajectories)
Description of Capsule
Landing and Location Systems
Retrieving System
Access to Capsule Interior

General Mission Description

The basic objective of Project Mercury is manned orbital flight with a safe return of the man from orbit. The orbital flight program, first unmanned and then with animals, will follow a progressive buildup of suborbital tests which are now in progress. The Atlas propulsion and radio - inertial guidance system will be used to place the 2400 pound capsule into a 105 nautical mile altitude, 32.5° inclination orbit with a resulting period of approximately 90 minutes. The launch will be from the Air Force Missile Test Center at Cape Canaveral, Florida and the insertion into orbit is expected to be at a point approximately half-way to Bermuda. It is expected that insertion altitude will be attained within one mile of the desired value and the variation over the orbital cycle will be less than ten miles. If it appears from the real-time tracking and computing data that tolerable orbit characteristics will not be met, controlled firing of the retro-rockets will be initiated to land the capsule short of the African coast near the Canary Islands. In the event of a malfunction at any time during the launch phase, emergency procedures will permit a water landing which could take place almost anywhere between Cape Canaveral and the west coast of Africa. Figure 1 shows the sequence of operations for various abort conditions and for normal operation of the capsule system. For off-the-pad and low altitude aborts, the capsule is pulled up off the nose of the Atlas by an escape rocket mounted on a tower above it. For high altitudes, after the escape-rocket tower has been jettisoned, the capsule retro-rockets are used to assist the separation action. At still greater altitudes essentially the same sequence is followed as for normal re-entry from orbit: i.e., the hot gas jets are used to orient the capsule in a heat-sink-forward (and up) attitude and the retro-rockets fired to hasten the deceleration and return to earth by parachute.

Initial orbital flights are planned for three orbital cycles with a water landing along the Atlantic Missile Range near San Salvador Island at the end of the third cycle. In the event of an in-flight emergency, provision is also made to land the capsule after completing its first or second orbit. Planned recovery areas are shown in Figure 46 ; ground track for the three orbits is shown in Figure 60 ; trajectories, in Figures 2 and 3 .

CAPSULE FLIGHT SEQUENCE OF OPERATIONS

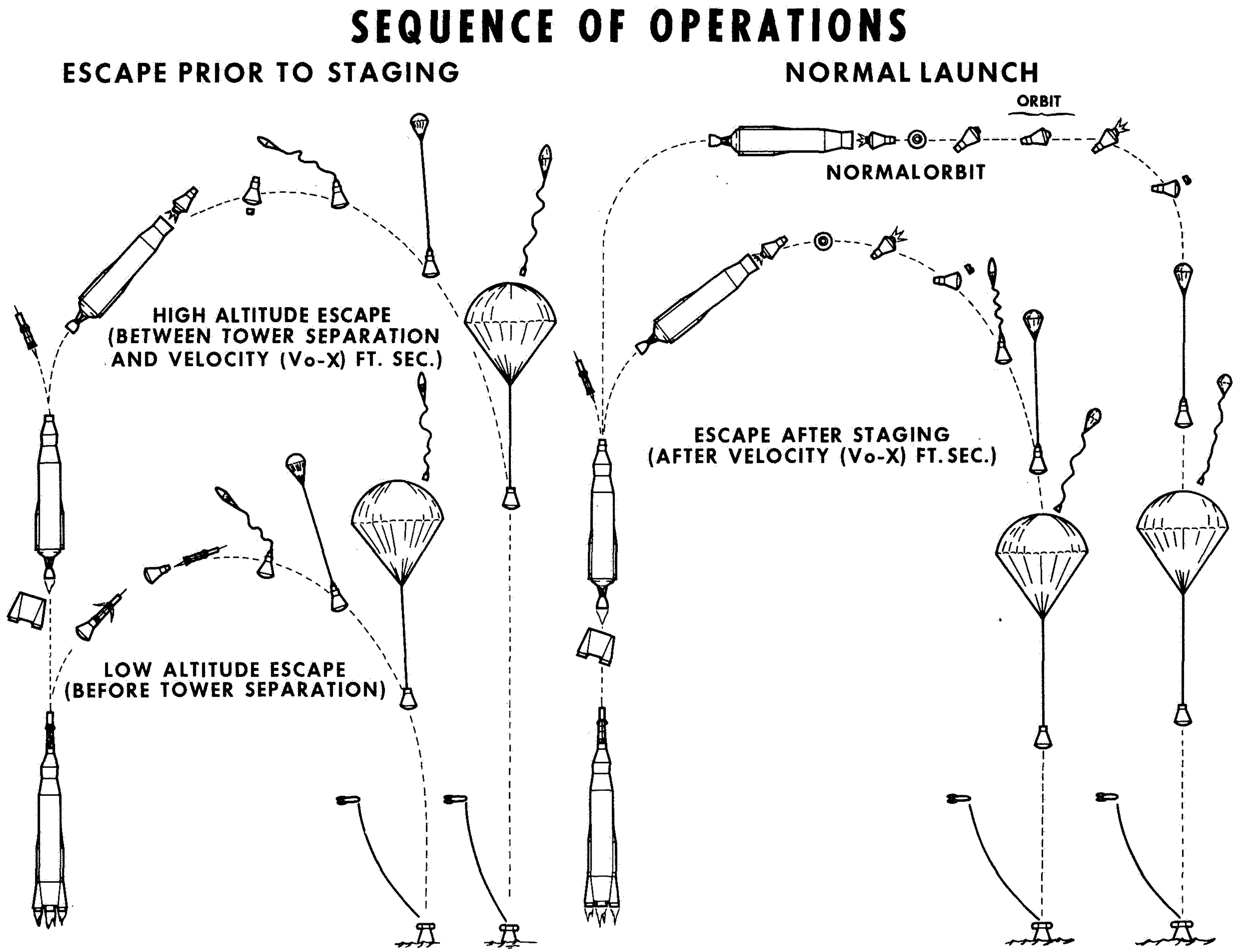

Fig. 1

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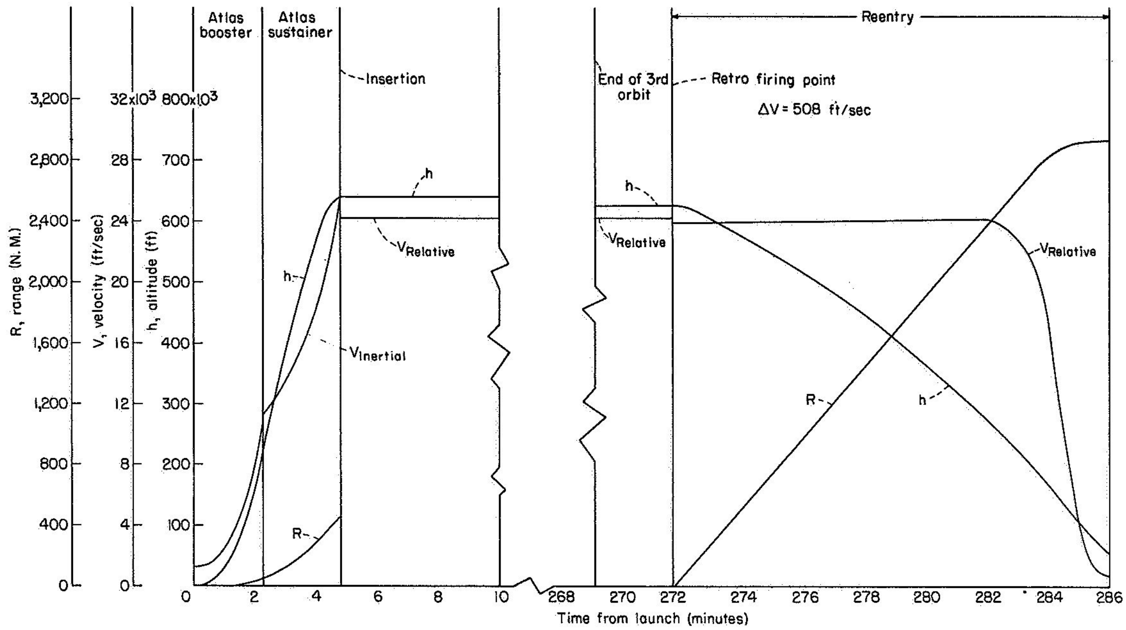

Launch, orbital, and reentry velocity, altitude, and range for the nominal 105 N. M. orbit.

Fig. 2

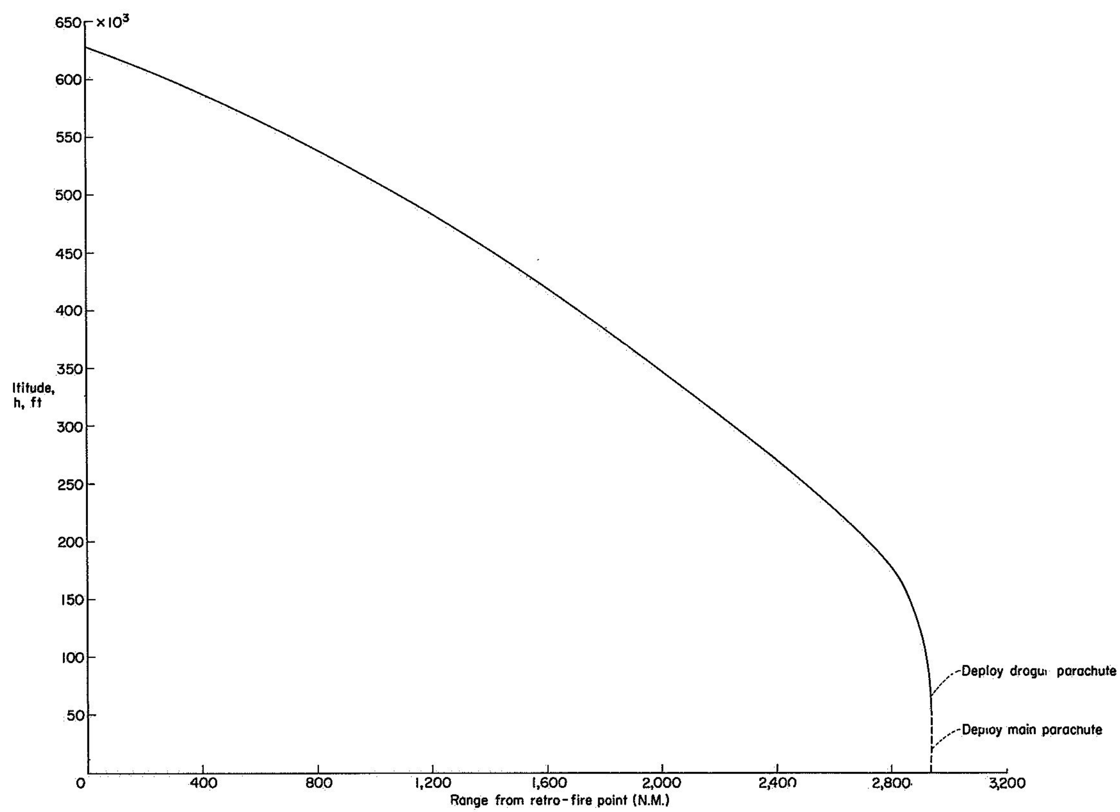

Figure . - Reentry profile (ΔV = 508 ft/sec)

Fig. 3

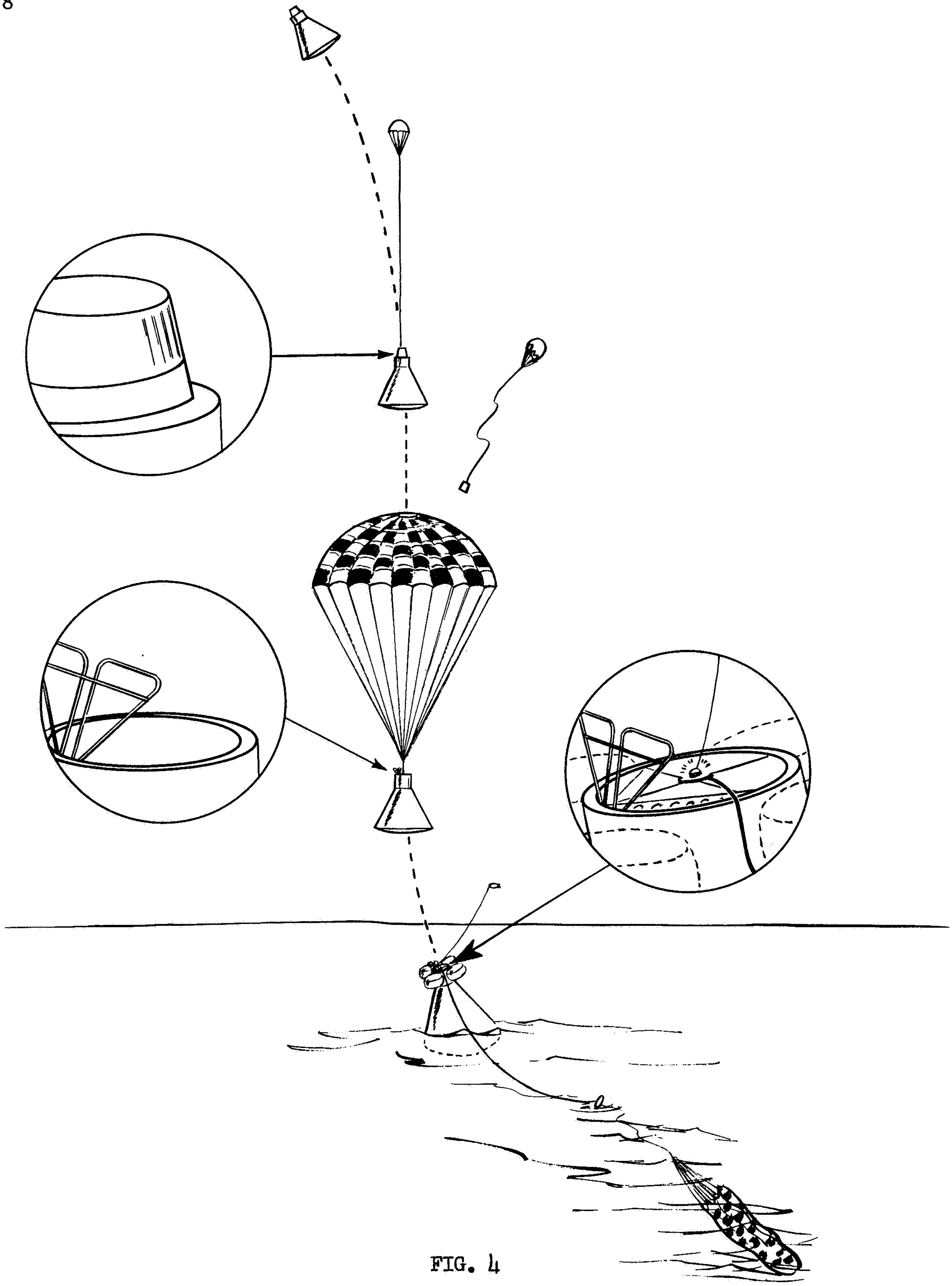

FIG. 4

DESCENT CONFIGURATIONS

Description of Capsule

Figure 4 shows the capsule in the descent and recovery configurations a) during re-entry, b) as it should appear for 2.4 minutes between 68,000' and 10,000' with the drogue chute deployed, c) as it may look for 5.4 minutes while descending under the main parachute from 10,000' altitude down to sea level, and d) as it is expected to appear five minutes after landing on the water. The capsule may be described as a frustrum of a cone with a short cylinder on top and a spherical surface on the bottom. The cone is 58.38 inches high, 74.5 inches in diameter at the base and 32 inches in diameter at the top. The cylinder is approximately 20 inches high and the spherical bottom has an 80 inch radius. The top is expected to float about 5½ feet above the water, the exact value depending upon the final weight and the amount of water that may be taken aboard between the rather loose fitting outer skin shingles and the inner pressurized cabin. The dry recovery weight is expected to be approximately 1750 lbs., but pickup weight for retrieving operations is assumed to be 2500 lbs. The pilot lies on his back in a contoured couch near the base of the capsule with crushable, energy-absorbing material between him and the bottom. Parachutes and other recovery aids are housed in the cylinder on top, and the design is presently such that the pilot may climb out the top by first removing a portion of his instrument panel, removing and stowing the pressure bulkhead door at the top of his compartment, and then pushing out ahead of him the container for the main and reserve parachutes.

Four cylindrical flotation bags, three feet in diameter and two feet deep are clustered about the top of the capsule. Although the capsule is relatively stable in the water with the pilot in his seat, it becomes unstable during egress and these flotation bags prevent the egress end of the capsule from going below the surface of the water in the event the pilot should attempt to climb out.

The landing system and location aids are discussed in the following section. A more detailed description of the capsule and its systems is contained in Reference 27 .

Landing and Location Systems

Figure 4 shows most of the visible components of the capsule landing and location systems. These and other electrical, visual and acoustic location aids are discussed roughly in the order in which they come into use from re-entry on down until the capsule reaches equilibrium on the surface of the water. The descent and landing operations are divided for discussion purposes into the following phases:

Re-entry
Drogue Chute Descent
Main Parachute Descent
After Impact
Components

COMMUNICATIONS, TELEMETRY AND TRACKING EQUIPMENT

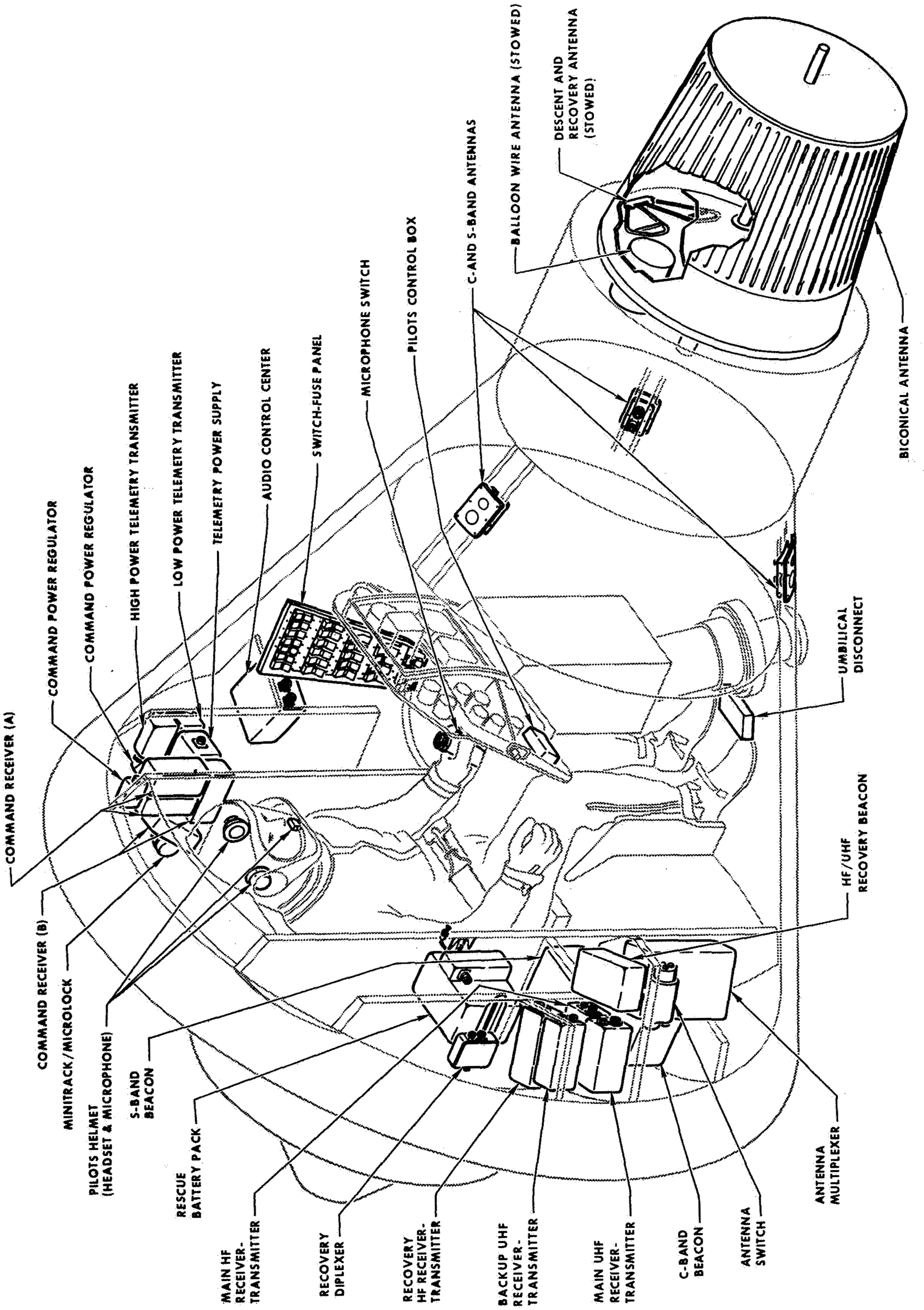

Fig. 5

CAPSULE INBOARD PROFILE SHOWING
ELECTRONICS COMPONENTS

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Table 2 summarizes the characteristics of the electronic aids and the time periods during which they are active.

Re-entry

During the approximately 14 minute period that it takes the capsule to descent from orbit to Mach 1 at about 68000 feet (covering a range of close to 3000 miles), electrical signals are transmitted on 7 different wave lengths for tracking and data recording purposes (Table 2). For the planned recovery after the third orbit or for emergency return after either the first or second orbits, this re-entry will take place over the southern U.S. where good tracking facilities are to be available for accurately predicting the impact point. In addition to signals from the C- and S-band beacons, UHF and HF voice, two telemetry beacons and the minitrack beacon transmissions, it may be possible also to get a return from some skin tracking systems. The capsule main antenna consists of a bicone contained within a band of dielectric between the parachute compartment and the drogue chute container. It serves to isolate the two portions of the vehicle for HF operation and also serves as a biconical horn for the various UHF frequencies. The radar beacons use independent, flush-mounted helical antennae (three each) located near the top of the conical body of the capsule. Figure 5 shows the main avionic equipment installed.

Drogue Chute Descent

Although the capsule alone is aerodynamically stable during re-entry, undamped oscillations may become divergent and result in tumbling at lower speeds and altitudes and a small drogue parachute is therefore deployed for stabilization at approximately 68000 feet and Mach 1.0. This drogue chute is a six foot diameter, FIST ribbon type with radar reflection characteristics. As a radar target the metalized drogue chute is assumed equivalent to a 1.6 sq. meter target. A 45 foot bridle connects it to the antenna fairing from which it is forcibly ejected upon signal initiated by altitude-sensing barostats. Drogue chute descent to 10000 feet will take approximately 2.4 minutes, during which all the electrical transmissions described as operating throughout the re-entry phase will continue to operate. Provision is made for the pilot to manually fire the drogue mortar in the event that it fails to function automatically. At 20000 feet, ventilation air inlet and exhaust valves will be actuated.

Main Parachute Descent

Barostats are designed to initiate main chute deployment at 10000 feet by causing the release of the antenna fairing which, in combination with the drogue chute, acts to pull the main parachute from its compartment. Velocity at deployment is approximately 200 feet per second. A load sensor will detect failure of the main parachute and will initiate subsequent deployment of a pilot chute and main reserve chute on unmanned flights. On

manned flights the pilot will control the reserve system. The main chute deployment sequencing remains independent of the drogue system, and the main parachutes, which are 63 feet in diameter, reefed, ringsail types, are designed to effect positive deployment under the higher speed condition resulting from drogue chute failure. Although the main parachutes are not metalized, radar reflective chaff which will be equivalent to at least a 600 square foot target, will be dispensed with the deployment of either chute.

With release of the antenna fairing at 10000 feet, the drogue chute may cease to be a tracking aid (it will probably collapse); the HF voice and minitrack signals stop. UHF voice and telemetry signals are transferred from the biconical antenna to a new fan monopole antenna (Figure 4) which swings up by spring loading when the material above the parachute compartment is jettisoned. In addition, the 243 mc SARAH beacon pulses commence from this antenna. S- and C-band beacon operation need not be affected since these beacons are located below the parachute compartment. Although it is presently planned to shut down the S- and C-band beacons at 10000 feet to conserve power, it would seem advisable on the first orbital flights at least, that at this point they should be made capable of being triggered by search aircraft for added redundancy in the location aids.

<u>After Impact</u>

Capsule impact (approximately 30 fps) actuates a pair of inertia switches which arm or operate some of the recovery aids. Upon normal landing with the main chute, the inertia switch actuates the main chute jettison squib, turns off electrical systems no longer needed, turns on the rescue beacon, HF back-up transceiver, the UHF back-up transceiver, and the recovery flashing light. It arms the pilot operated "rescue switch", actuation of which will then disconnect the reserve chute and fire the pilot chute deployment gun and the reserve chute ejector bag if these have not already been fired to deploy the reserve chute during landing. Along with the reserve chute when it is jettisoned will go 3 packs of dye marker (attached to the capsule by a string), a packet of chaff and 2 SOFAR bombs. The four flotation bag compartment covers will be ejected from the capsule by squib cartridges at this same signal and the bags will fill with air. After $2\frac{1}{2}$ minutes the high lift/drag balloon will fill with helium and will raise the light-weight, 30 foot wire HF antenna. The 8.364 mc HF rescue beacon will come on automatically as well as the separate HF recovery voice transmitter, and both will use this elevated wire. A separate battery supply will power both HF and UHF recovery voice transmitter/receivers. The impact sensor also initiates the ejection cycle for the smoke generators in the automatic mode (six cartridges, one every 30 minutes) or arms this circuit for manual firing by pilot.

If the capsule should land during a period of near-zero wind, it is highly possible for the parachute canopy to settle partly or completely over the capsule. This possibility presents a hazard in several ways. The flashing

TABLE 2

TIMING AND CHARACTERISTICS OF MERCURY CAPSULE LOCATION AIDS DURING DESCENT AND RECOVERY PERIOD - EARLY ORBITAL FLIGHTS

Mercury Capsule Equipment	Effective Time Period: Retro Rocket Firing → Drogue (14 min.)	Drogue → Main (2.4 min)	Main → Impact (5.3 min.)	Impact → Balloon Antenna Erected (2.5 to 5.0 min.)	Balloon Antenna Erected → (?)	Echo Area	Electronic Characteristics: Frequency (Mc)	Antenna Gain (See notes below for pattern)	Power Output (watts)	Modulation Method
1. C-Band Beacon triggered by FPS-16, free running or locally triggered.	H (possible)		(planned)	H			5480 (1) interrogate 5555 transmit	-6 db right hand polarization	400 peak	pulse (rep rate per FPS-16)
2. S-Band Beacon triggered by MOD II free running or locally triggered.	H (possible)		(planned)	H			2900 (1) interrogate 2940 transmit	-6 db left hand polarization	1000 peak	pulse (rep rate per Verlort, MOD II)
3. UHF Voice	BH		D/R	(Backup)	D/R		296.8	-1 db (2 db after main chute, if used)	2	AM
4. UHF beacon/voice	(Backup)	BH	D/R		D/R		296.8	+ 2 db (-1db before main)	½	CW/AM
5. UHF telemetry (A)		BH	D/R				227.2	-2 (+2 after main)	3.3	FM
(B)		BH	D/R				259.7	-2 (+2 after main)	3.3	FM
6. SARAH beacon			D/R				243	+2 db (approx.)	15 peak	pulse(double coded. 200 cps rep. rate)
7a. HF Voice (A)	BH		(no antenna available)				15 to 18	+ 5 db	10	AM
(B)					BB		15 to 18	+ 2 db	1	AM
7b. HF Beacon (SEASAVE)					BB		8.364	+ 2 db	1	CW
8. Minitrack Beacon	BH						108	-1 db	0.1	CW (some AM)
9. Radar reflection										
a. Capsule skin						.4 m² at S-band; 1.4 m² at C-band; 4.1 m² at X-band				
b. Drogue chute						1.6 m² at all bands				
c. Chaff						56 m² at all bands				
10. Visible reflection										
a. Smoke				☼	☼☼☼☼					
b. Dye Marker										
c. Capsule Skin										
d. Floating Parachute				(not presently planned)						
11. Flashing light				++++++++++++++++++	++++					
12. SOFAR bomb					☼☼					

Antennas:
- H = Helical antenna for C and S-band beacons; the peaks of the multi-lobed pattern are circular within a few db.
- BH = Biconical horn antenna for UHF,VHF,HF; no pattern data available during study. Assumed essentially circular.
- D/R = Descent/recovery antenna for UHF; somewhat elliptical pattern.
- BB = Balloon-borne antenna for HF; circular pattern.

Notes: (1) These frequencies are those selected for the tests known as "Big Joe". It is recommended that the S-band beacon be made compatible with the AN/APS-20 radar in order to enhance detection by recovery forces in the impact area.

(2) Antenna gains and patterns are those in a horizontal plane with capsule axis vertical.

light would be covered and the extension of the balloon-supported HF antenna would be prevented. Furthermore, the fresh air ventilation system would be penalized, all other antennae would be partially shielded, and the pilot might encounter difficulty in pushing the parachute container out ahead of him should he attempt to climb out the top. Somewhat compensating factors would be the large visual target provided by the parachute during search and the ease of recovery provided by the absence of wind (and calm seas). Nevertheless, it appears desirable to provide means of either preventing the parachute from settling over the capsule, or removing it if it should. The data in Table 23 show the probability of encountering winds of less than 4 or 6 knots for the different landing areas by month of the year.

Although visibility of the main parachute during descent will be enhanced by the alternate orange and white gores, this advantage is lost after landing in the water because the parachute is not a floating type and would soon sink. Some parachute makers claim that a process which makes the parachute floatable has been developed which does not change the cloth permeability enough to exceed specification limits. If such a material could be used without adversely affecting the parachute behavior it would greatly improve the chances of visual detection of the capsule on the water, especially from the air.

Components

Parachutes - are believed to be described adequately in the preceding sections.

Electronic Aids - including chaff are described above and also in Tables 6 , 8 , and 13 .

SOFAR Bombs - Three SOFAR bombs are provided. Two are ejected with the reserve parachute, to detonate at 3500 and 4000 foot depths, respectively. The third bomb remains with the capsule to send a signal if the capsule sinks.

Dye Marker - Three packs of dye marker in a water soluble container are ejected with the reserve parachute to aid in visual location during the search phase. The container remains attached to the capsule by a retainer line.

Smoke Generators - mounted in the top of the capsule, to aid in visual detection after impact, may be ejected by pilot action or by the automatic mode. Made by Ordnance Research and Development Corporation, the white smoke is generated for one minute per cartridge (6) and is to be visible for a 10 mile distance.

Flashing Light - A high intensity flashing recovery light is mounted slightly above the plane of the capsule top. It has a flash rate of at least 15 per minute, and from 12000 feet or below it may be seen at a distance of 50 miles on a moonless, starlit night with 90% humidity. Care must be taken in the final design to assure that the light is raised as high as possible to reduce the likelihood of its being hidden by flotation bags or by the edge of the capsule if it should heel to leeward.

Survival Equipment - The capsule is equipped with a survival kit attached to the pilot by a lanyard and a survival type knife is provided in a sheath on the pressure suit. A flashlight is also furnished. Survival kit equipment includes:

1	PK-2 Raft	3	Distress Signals, Day & Night
1	Desalting Kit	1	Signal Mirror
2	Shark Chasers	1	PRC-32 Radio
3	Dye Markers	1	Survival Ration
1	First Aid Kit	1	Lighter plus extra Fuel and Flints or Matches

Retrieving System

Although the pros and cons of various aids for picking up the capsule are discussed later in detail, a few remarks are thought to be appropriate here because the most promising schemes appear to require some change in the design of the capsule. After studying the various vehicles that might be involved and the variety of techniques available to each it is concluded that there ought to be something permanently attached to the capsule which can be conveniently caught, hooked, or grasped and by which the capsule may then be lifted out of the water. Certain dummy capsules equipped with hooks on the cylinder sides near the top have been successfully and quickly picked up in practice using a helicopter with a small drag net (Figure 24). However, because inflation bags would certainly interfere with this method, and the weight of the hooks, designed to withstand re-entry temperatures, might be excessive, it is thought best not to count on such hooks for recovery of the orbital vehicles.

It has been assumed as a general ground-rule for this study, therefore, that the capsule exterior will be relatively smooth, free of handy hooks, etc. and that flotation bags will be inflated at the time pickup is attempted.

The most versatile retrieving aid appears to be a floating pickup line (Figure 17). This might be deployed upon impact or attached to the main or reserve parachute riser so that it is carried out into the water when the parachute is jettisoned. In the form of a loop or with a special fitting at the end, it is believed that such a line could be used to retrieve the capsule from any vehicle that could lift the weight. With other smaller vehicles it could be useful for towing, maneuvering or keeping the capsule afloat. The next best arrangement would be one in which a handy bail, loop, hook or eye were exposed and readily available on the top of the capsule through which someone could insert a hook or pickup line (Figure 19). The retrieve could then be accomplished as in the previous example.

It is therefore recommended, in the interest of a rapid pickup by the greatest variety of vehicles which might be employed, that serious consideration be given to the best means of providing such aids in the capsule design.

Access to Capsule Interior

In the present capsule design the pilot can climb out through the top but not out the side hatch through which he entered. Rescuers, working from the outside, can get at the occupant from the side hatch but cannot get him out through the top.

For this study the occupant is assumed to remain within the capsule, and access time (as it is used herein) includes the time required to place the capsule at the disposal of an astromedical team, but no allowance has been made for the time required to open up the capsule. It is assumed that airships or HR2S-1 helicopters assigned to recovery operations will have simple platforms added (Figures 20a and 20b) from which the capsule side may be opened and the occupant examined or removed to a couch. Outer skin shingles can probably be most readily removed by ripping them off with pliers. Nuts may then be removed and the sealed inner hatch opened. If the pilot is incapacitated it will be necessary for someone to reach into the capsule to release the restraint harness and other attachments (oxygen, survival kit, etc.) before removing him. This time-consuming process is hardly an operation to be conducted while the capsule is floating in the water unless the seas are quite calm, and unless a quicker method is developed for gaining access through the side, the capsule must be secured to or near a high and dry platform before the pilot can be reached.

APPLICABLE VEHICLES

The selection of vehicles applicable to one or more phases of the Mercury capsule recovery operation is dependent upon several factors. Among the most important factors, this section is concerned primarily with:

* Performance capabilities or characteristics, such as speed, range, and usable altitude for aircraft.

* Numbers in active service.

* Apparent general suitability to such functional tasks as search, recovery, and local area CIC or coordination.

Additional factors of particular interest are the types of installed equipment applicable to:

* Communications
* Navigation
* Radar tracking and search
* Local area CIC or coordination
* Retrieving the capsule from the water

Each of these factors is discussed in the most appropriate section of this report.

In assessing the apparent general suitability of various vehicle types to the several functional tasks to be performed, it is convenient, as a first step, to examine ships and aircraft types separately. The pertinent characteristics of each broad grouping may thus be presented in the simplest form.

Table 3 summarizes the operating characteristics and numbers available for the major ships in active service with the U.S. Navy, U.S. Coast Guard, and the Atlantic Missile Range, plus a good number of auxiliary vessels. The list is set up in order of decreasing vessel speed, beginning with destroyers, the most plentiful single type on the Navy active list. For the purposes of this study, each type of ship has been assigned an operational speed, representative of the speed which may be maintained for a few hour period in up to sea state 3 or low sea state 4. The operational speed represents a 20 to 40% reduction from rated speed, depending on vessel type. At the far right of the table, notes relative to suitability for certain functional tasks are included. The most significant feature of this table is the indication that most vessel types are active in only limited numbers, especially if attention is directed only to the number active in the Atlantic fleets. Secondly, it is significant that most types are considered applicable to the recovery operation because a retrieve technique has been developed (e.g., destroyers), or because hoist capability and deck space on which to set the capsule are available (e.g., cruisers, sub rescue). The AMR ships are, of course, applicable by the very nature of their installed electronic equipment and of their area of operation.

TABLE 3

Evaluation of Ships for Applicability

Type	Number LANT	Active PAC	Speed-Knots Rated	Oper(1)	Remarks
1. Navy					
Destroyer: DD, DDE, DDG	118	86	33	25	Des Flot Four has developed recovery technique
DDR	20	16	33	25	(Destroyer at rest, capsule alongside)
Frigate: DL	3	2	32	25	
Cruiser: CA	4	7	33	25	Carry helicopter, have stern hoist and deck space
CL		2	32	25	" " " " " "
CAG	2		33	25	
CLC	1		33	25	Carry helicopter
Carrier: CVA, CVS	11	14	33	25	Could carry AEW and search aircraft, helicopters
Escort: DE	18	16	21	15	Probably can use destroyer technique.
DER	17	19	21	15	
Seaplane Tender: AV	1	4	18	15	Seaplane handling gear should be satisfactory.
High Speed Transport: APD	1	5	23	15	Probably have hoist capability and deck space.
Submarine: SSN	2		20	15	Should be able to approach capsule with decks awash for pick-up from below.
SS (Guppy)	37	26	20	15	
SS (Other)	21	6	20	15	
SSR	5	5	20	15	
Misc.	9	6			
LSD (Thomaston Class)	4	4	24	15	Carry HUS helicopters (not HR2S due to rotor size) and LSU's, both having pick-up capability.
Carriers: T-CVU	2	2	19	15	Used for ferry purposes.
CVHA		1	19	15	Marine assault helicopter carrier.
Fleet Tug: ATF	11	19	16	10	Some carry salvage gear.
LSD (Ashland/Casa Grande)	6	11	15	10	See note for LSD (Thomaston Class).
Sub Rescue: ASR	6	4	15	10	Hoist and deck space for 10½ ton rescue chamber.
Transport: AKA	8	8	16	10	Probably have hoist capability and deck space.
APA	6	15	16	10	" " " " " "
Ammunition: AE	6	7	15	10	" " " " " "
Dest. Tender: AD	9	6	18	10	" " " " " "
Icebreaker: AGB	3	2	16	10	Carry helicopter.
Minesweeper: MSO, MSF	30	31	15	10	Probably require modification to handle capsule.
Patrol: PC, PCE, PCE(R)	12	2	16	10	Probably not suitable due to size and sea capability.
Aux. Ocean Tug: ATA	11	8	13	8	Some carry salvage gear.
Cable Repair: ARC	3	1	12	8	Cable handling gear may be usable for capsule.
Net Layer: AN	5	5	12	8	Net handling gear may be usable for capsule.
LST	12	39	11	5	Could carry helicopter with modification.
2. Coast Guard					
Buoy Tender: WAGL	22	19	12	10	Good retrieve capability.
Ocean Tug: WAT, WATF	4	2	14	10	
Ice Breaker: WAGB	2	1	16	10	Carry helicopter
Cutter: WPG	10	8	18	10	Probably not suitable for pick-up according to C.G.
Weather: WAVP	13	2	18	10	
Buoy Tender: WAGL	5		8-11	5-8	Good retrieve capability
3. AMR					
FS (AKL)	6		12	8	Telemetry
C1-M-AVI (AK)	5		11	8	Telemetry
DAMP	1				American Mariner, has equivalent of two FPS-16 radar.
VC2-AP2		1			Pvt. Joe E. Mann, telemetry

Note: (1) Assumed operational speed, considering up to Sea State 3 or low Sea State 4.

In Table 4 , the performance capabilities of a large number of aircraft types of particular interest are summarized; fixed wing, helicopter, and airship types are included. Supplementary data regarding assumed gross weights and fuel loadings are shown in Table 5 . In order to complete the presentation of aircraft performance capabilities, the complete variation of attainable time on station with station radius is given in Figure 6 for each aircraft type. It is evident that there is a wide spread in airplane performance available, up to rather extensive time on station capabilities. The very long endurance capabilities of airships are especially notable.

Each one of the necessary functional tasks calls for certain basic qualities in vehicles and personnel. In broadest terms, some of these are as follows:

1. In providing radar early warning coverage of an area or region, there is a significant radar range advantage to placing the radar observer in an aircraft operating at altitude, because of the increase in horizon limited line of sight distance thus obtainable. This is illustrated by Figure 7 which shows, for example, an increase of 150 nautical miles in horizon distance between sea level and 15,000 feet altitude. Given sufficient radar power, then, substantially greater area coverage per observer can be obtained by use of aircraft such as the WV-2 (or RC-121D). If the target to be detected, the manned capsule in this instance, is cooperative as contrasted to non-cooperative, somewhat similar coverage capabilities can be obtained using considerably less powerful radars, such as would be found in most military service aircraft. For pressurized piston-engine aircraft, a station altitude of 15,000 feet is considered reasonable as being attainable at economical fuel consumption power settings. For unpressurized aircraft, it is considered that altitude should be limited to 10,000 feet in the interests of crew comfort and operational efficiency. In all cases, these altitudes are less than service ceiling, which generally occurs between 20,000 feet and 30,000 feet.

2. Although surface ships have severely limited radar range against surface targets, many have radar which can be used to detect the capsule during its descent at altitude.

3. Search and rescue experience through the years has disclosed that it is extremely desirable to use airborne observers for visual search. This is especially true if the observers are trained and experienced. By this means, a very large area can be searched in a given length of time; and in addition, search of an area located at some distance from the search vehicles can be begun sooner. Further, it has been found preferable to use moderate speed aircraft in order to gain the most satisfactory compromise between area vs. time on the one hand, and speed of passing an object on the other. A high passage speed is definitely not of prime value since it introduces some confusion in identifying real or apparent visual images.

4. The first requisite of a retrieve vehicle is the ability to remove the capsule from the water and then carry it. At the present state of the art of picking up heavy objects, this phase of the operation must be performed

TABLE 4

Summary of Aircraft Characteristics

Type	Number Navy[1]	Active USAF[2]	C.G.[2]	Airspeed-Knots Cruise[3]	Search[4]	Maximum Radius[3]-n.mi.	Maximum Endurance[4]-hr.	Pick-up[5] Radius-n.mi.	Radar Band	Remarks
1. Fixed Wing										
S2F-1/2	125			130	130	420	6.5	-	X	search
SA-16A/UF-1	17	100+	35	135	120	1,120	18.5	-	X	search, possible landing for access to capsule occupant
R4Y/C-131	16			160	120	1,120	19.0	-		search, pressurized
SA-16B/UF-2		85	34	135	105	1,350	24.0	-	X	search, possible landing for access to capsule occupant
P5M-2	24			150	120	1,510	22.4	-	C	search, possible landing for access to capsule occupant
R5D/C-54	13			156	110	1,950	29.6	-	X	search
P2V-5/7	140			170	150	1,810	23.6	-	S	AEW
WV-2/RC-121D	42	36[6]		215	180	1,960	23.3	-	S	AEW, pressurized
C-119				146		1,050	14.4			Aerial pick-up, winch recovery system installed in about 50 aircraft.
C-130A				290	125	1,350	7.6			All American Engineering indicates C-130 would be better than C-119 for aerial pick-up.
KC-97G				205	180	2,720	35.2	-		suggested for SAC support of world-wide search outside high probability areas.
B-52D				460	204	3,800	16.2	-		
B-47				410	210	2,240	10.3	-		
KC-135				455	200	3,380	14.2	-		
R3Y, Tradewind										10 in mothballs } all have long range, hoist capability, and hatch for pick-up and taking capsule aboard.
JRM, Mars				160		2,500+				sold for commercial purposes } all have long range, hoist capability, and hatch for pick-up and taking capsule aboard.
2. Helicopter										
HR2S/H-37/S-56	100+[7]			90				165[8]		capsule can be winched part way into fuselage and occupant removed; can carry medical team.
H-21/V-44	800+[7]			85				120[8]		carry capsule suspended.
HUS/HSS/S-58	1000+[7]			85				265[9]		
3. Airship										
ZPG-2/2W	9			40	40	2,000	100	2,000	S	some AEW versions; capsule can be winched up to car and occupant removed; can carry medical team.
ZPG-3W	1									
ZS2G-1	6			50	50	1,500	60	1,500	X	lift capability in doubt due to small envelope size.

Notes:
1. Number assigned to Atlantic Fleet
2. Total
3. Best cruise altitude, long range airspeed
4. 1,500 ft. altitude
5. 2,500 lb. pick-up
6. Approximate number assigned to East Coast
7. Total produced
8. Zero wind value shown; reduced for 20 knot wind to approximately 130 n. mi. (HR2S) and 95 n. mi. (H-21)
9. Zero wind, dry day value shown; extra fuel used.

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TABLE 5

Summary of Aircraft Weights and Fuel Loads

	Aircraft	Take-off Weight - Lb. Maximum	Assumed(1)	Operating Weight-Lb.	Fuel Load-Lb.	Mission Fuel-Lb.
1.	Fixed Wing					
	S2F-1	24,300	23,500	20,400	3,100	2,900
	SA-16A/UF-1	34,000	33,900	23,900	10,000	9,300
	R4Y/C-131	47,000	40,400	30,000	10,400	9,400
	SA-16B/UF-2	36,500	36,100	26,100	10,000	9,300
	P5M-2	85,000	76,700	53,000	23,700	21,200
	R5D/C-54	73,000	63,700	41,400	21,200	19,900
	P2V-5/7	80,000	77,200	51,600	25,200	23,500
	WV-2/RC-121D	146,300	146,300	92,100	52,600	49,300
	C-119	72,700	59,000	43,500	15,500	
	C-130A	124,200	92,400	61,100	31,300	28,100
	KC-97G	175,000	175,000	93,000	82,000	77,200
	B-52D	450,000	430,000	152,000	270,000	243,000
	B-47	220,000	210,000	86,000	118,000	106,000
	KC-135	275,000	275,000	99,000	171,000	154,000
2.	Helicopter					
	HR2S	31,000	29,300	20,900	6,900	6,200
	H-21	14,400	11,900	10,100	1,800	1,600
	HUS	13,600	13,000	9,000	2,900(2)	
3.	Airship					
	ZPG-2/2W				12,000	11,000
	ZPG-3					
	ZS2G					

Note: 1. Applicable to assumed mission, radius and endurance data in Table 4.
2. Includes extra fuel.

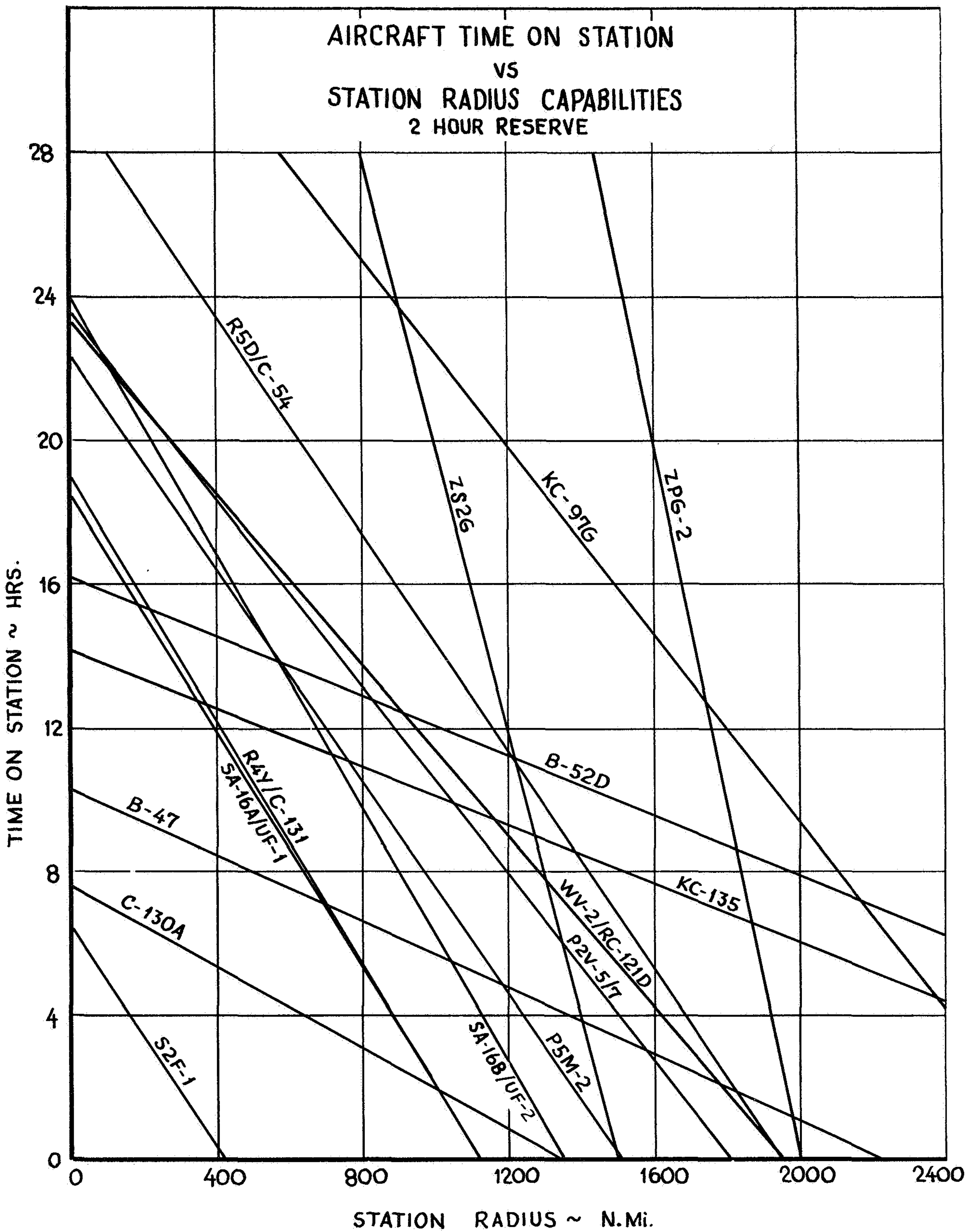
AIRCRAFT TIME ON STATION
VS
STATION RADIUS CAPABILITIES
2 HOUR RESERVE
TIME ON STATION ~ HRS.
STATION RADIUS ~ N.Mi.
0
4
8
12
16
20
24
28
0
400
800
1200
1600
2000
2400
R5D/C-54
ZS2G
KC-97G
ZPG-2
B-52D
KC-135
B-47
R4Y/C-131
SA-16A/UF-1
C-130A
WV-2/RC-121D
P2V-5/7
S2F-1
SA-16B/UF-2
P5M-2

Fig. 6

at or close to zero forward speed. Therefore, fixed wing aircraft may be ruled out for the present, although not necessarily for the future; future possibilities using fixed wing aircraft are discussed in a later section. The other vehicles are all applicable in one area or another. Helicopters are characteristically limited in range and time in the air capability, so must in most cases be restricted to land-based operations. Airships are roughly twice as fast as destroyers and are capable of considerable endurance, but are characteristically sensitive to headwinds; therefore, they are not generally operated at large distances from base, but would presumably be usable somewhat beyond helicopter distance coverage. Ships, both surface and submarine, are characterized by long endurance measured in days, rather than in hours as for aircraft, and would therefore be selected for the more remote areas.

5. For local area CIC or coordination, the vehicle characteristics most desirable would be large space available for communications and other search operational personnel and for equipment such as chart plotting boards, plus the ability to obtain a good navigational fix on position. Logically, a ship would be preferred, followed by airships and large fixed wing aircraft.

On the basis of the above considerations, a combined complex of ships, fixed wing aircraft, helicopters, and airships appears attractive:

1. Fixed wing aircraft for airborne radar coverage and visual search. An aircraft such as the WV-2 (or RC-121D) would be most desirable for radar coverage due to the radar equipment carried. Because of crew experience in anti-submarine (ASW) search and in search and rescue work, aircraft such as the S2F, SA-16, P5M, and P2V types would be desirable.*

2. Helicopters for retrieve close to land. A secondary reason for this selection is the versatility of the helicopter in the event of impact on land in an area of rough topography.

3. Airships for airborne radar coverage (because of equipment aboard), visual search (crews experienced in ASW work), and retrieve beyond helicopter range.

4. Ships for radar detection during capsule descent for retrieve in the more remote areas, and for local area CIC or coordination.

An additional use for ships, for specific types of ships, would be to provide coverage for an emergency such as sinking of the capsule in water shallow enough to permit rescue operations. Sub rescue ships, for example, are equipped with more than adequate hoist capability and are manned by experienced load handlers and divers.

*An additional aircraft type of particular interest would be the WF-2, a development of the S2F design currently entering service. The WF-2 combines the S-Band radar detection capability of the WV-2 with the visual search qualities of the S2F, unfortunately also with the limited endurance of the S2F.

APPLICABLE ELECTRONIC EQUIPMENT

Grouped under the heading of applicable electronic equipment are those airborne, shipboard and shore-based units which aid the recovery of the Mercury capsule through their ability to provide suitable means of communication, navigation, detection and homing. Such equipment is divided for detailed consideration, as follows:

- Ranging and Homing Equipment
  - Active Radar
  - Passive Radar
  - ECM Receiving and Homing
  - UHF Homing
  - SARAH System
  - HF Homing
  - VHF Homing
  - Acoustic Detection
  - Miscellaneous
- Communication Equipment
- Navigation Equipment

Ranging and Homing Equipment

Detection and tracking of the Mercury capsule in the local recovery area and from shore points depends upon the capability of equipment to range and/or home on the radiations emitted by or reflected from the capsule. The capsule's devices, systems, recovery aids and general features which afford a means of detection (hereafter referred to as "detectable features") are listed in Table 6 . Applicable means of detecting each of these features and specific equipment for accomplishing the detection by appropriate types of aircraft, classes of ship, and shore installations are also given in Table 6 . Table 6 is not to be considered complete. Except for recent backfits, data on equipment installed in Navy aircraft are considered complete. Less is known about Air Force aircraft (except SA-16) and ships.

Of the detectors listed, only active radar permits determination of range to capsule at one location at one time. All others require triangulation, rate of change of bearing at known speed, or similar scheme to establish approximate range.

Characteristics of the capsule's detectable features are given previously in Table 2 . Characteristics of the various detectors, insofar as it has been possible to obtain them, are given below. Effective ranges for each appropriate detectable feature-detector combination have been calculated, as far as practicable. The methods for computing ranges are described below, while the ranges themselves are given in Table 8 . Various assumptions regarding effects on equipment performance, and hence range, of such matters as weather, service life, state of maintenance, and alertness of operator are discussed. Because of these

assumptions, the ranges of Table 8 should be considered relative rather than absolute. In calculating ranges, limitations of the horizon have been ignored, since such limitations are in the application and not the system itself.

Active Radar

Measured as an area, radar reflectivity is defined as 4π times the ratio of power per unit solid angle scattered back toward the transmitter to the power per unit area striking the target. (Reference 58). An active radar is required to generate the original radiation. Characteristics of radars listed in Table 6 are shown in Table 7 .

Radar ranges have been calculated for a 50% probability of detection. Where ranges against known targets were available, they were approximately scaled to the capsule cross section and adjusted to 50% probability with due allowance being given to attenuation of the atmosphere. Where ranges to known targets were not found, equation (1), after Hall (Reference 54), was used.

$$R^4 \quad 10^{.2 \propto R10^{-3}} = \frac{PG^2 \lambda^2 \sigma}{(4\pi)^3 \quad KT \quad (1.2/\tau) \; N_f \; S} \qquad \text{Equation 1}$$

In equation (1),

R = range to target in meters.

$\propto$ = attenuation of atmosphere in db/kilometer based upon a sea level atmosphere at 70°F and 50% humidity. From Reference 54 , the following table was obtained:

Radar Band	(db/km)
L,S,C	0.010
X	0.018

P = peak power transmitted in watts.

G = antenna gain (dimensionless).

λ = wavelength in meters.

σ = effective capsule cross section (radar reflectivity) in square meters. Capsule area was determined from McDonnell Aircraft Corp. data (Reference 55) which gives capsule cross section measured at S-band and scaled to C-band by what appears to be a λ^{-2} factor. Median values were chosen at S- and C-band such that at half the aspect angles the cross section is greater and at half less than the value chosen. These values were scaled to other bands as necessary.

TABLE 6

CAPSULE DETECTABLE FEATURES AND DETECTION SYSTEMS

	Capsule Detectable Features	Capsule Detection by	S2F-1	P5M-1	P2V-(5F (6 (7	WV-2	UF-1 -2	ZPG-2	ZPG-2W	ZS2G-1	SC-54
1	Radar Reflection	Active Radar	APS-38A	APS-44A	APS-20B,-E APS-33B-(InP2V-6)	APS-20B,E APS-45(A)	APS-31,-31A -310	APS-20B,E	APS-20B -20E (APS-62)	APS-38A	APS-42
2	C-Band Beacon	(a) Passive Radar (b) ECM Receiver	-- APA-69A+APR-9B	APS-44A APR-9B+APA-69A ALR-3	-- APR-9B+APA-69C ALR-3	-- APR-9B+APA-69A,C ALR-3	-- --	-- APR-9B+APA-69A ALR-3	-- APR-9B+APA-69C ALR-3	-- APR-9B+APA-69C ALR-3	-- --
3	S-Band Beacon	(a) Passive Radar (b) ECM Receiver	-- APA-69A+APR-9B	-- APR-9B+APA-69A ALR-3	APS-20B,C,E APR-9B+APA-69C ALR-3	APS-20B,E APR-9B+APA-69C ALR-3	-- --	APS-20B,E APR-9B+APA-69A ALR-3	APS-20B,E APR-9B+APA-69C ALR-3	-- APR-9B+APA-69C ALR-3	-- --
4	UHF Voice	(a) UHF Homer	ARA-25	ARA-25	ARA-25	ARA-25	ARA-25	--	--	--	ARA-25
5	UHF Beacon/Voice	(b) ECM Receiver						ALR-8+APA-69A			
6	Telemeter	--	--	APR-13+APA-69A	APR-13+APA-69C	APR-13+APA-69A,C ALR-5	--		ALR-8+APA-69C ALR-5	APR-13+APA-69C ALR-5	--
7	UHF SARAH Type Beacon (243 mc)	(a) SARAH Receiver (b) ECM Receiver (243 mc)	-- --	-- APR-13+APA-69A	-- APR-13+APA-69C	-- APR-13+APA-69A,C ALR-5	-- --	-- ALR-8+APA-69A	-- ALR-8+APA-69C ALR-5	-- APR-13+APA-69C ALR-5	-- --
8 (a) (b)	HF Voice HF Beacon	HF Homer (3-30 mc)	--	--	--	--	--	--	--	--	--
9	Minitrack	(a) VHF Homer (b) ECM Receiver	-- --	ARN-14 APR-13+APA-69A	ARN-14 APR-13+APA-69C	ARN-14 APR-13+APA-69A,C ALR-5	ARA-8(A) ARN-14 --	ALR-8+APA-69A	-- ALR-8+APA-69C ALR-5	-- APR-13+APA-69C ALR-5	ARA-8 --
10 (a) (b) (c)	Smoke Dye Marker Reflected Sunlight	Eyeball									
11	Flashing Light	(a) Eyeball (b) IR Detector									
12	SOFAR Bomb	(a) Sonobuoy Rcvr. (b) MILS (c) SOFAR Net	ARR-26,-58	ARR-26,-58	ARR-26	--	--	--		ARR-26	--
13	Miscellaneous	(a) Searchlight (b) Sonar	AVQ-2A,2C	AVQ-2A,2C	AVQ-2A,2C	--	--	AQS-2		AQS-2	
Reference for installed equipment			56,61,70	56,61	56,61	61	61, 70, 83	56	61	56	71

TABLE 6 (Continued)

CAPSULE DETECTABLE FEATURES AND DETECTION SYSTEMS

	Capsule Detectable Features	Capsule Detection by	SA-16	SH-19	SH-21	JC-54	HUS-1 HSS-1 -1N	HR2S-1	H21 B (Air Force)	H21C (Army)	Navy Vessels		
											DD	DDE	AKL
1	Radar Reflection	Active Radar	APS-31	--	--	--	--	--	--	--	SR-B SPS-6C -8B -10 -28	SPS-6B SG-6 SR-6B *	SPS-58
2	C-Band Beacon	(a) Passive Radar	--	--	--		--	--	--	--	SPS-10	*	
		(b) ECM Receiver	--	--		Yes	--	--			BLR-1,SLR-2	*	--
3	S-Band Beacon	(a) Passive Radar	--	--	--	--	--	--	--	--	--	--	--
		(b) ECM Receiver	--	--		Yes	--	--			BLR-1,SLR-2	*	--
4	UHF Voice	(a) UHF Homer	ARA-25	ARA-25	ARA-25	ARA-25	ARA-25	ARA-25	ARA-25	--	URD-4	*	
5	UHF Beacon/Voice	(b) ECM Receiver	--	--	--	--	--	--	--	--	BLR-1,SLR-2	*	--
6	Telemeter		--	--	--	--	--	--	--	--		*	--
7	UHF SARAH Type Beacon (243 mc)	(a) SARAH Receiver	--	--	--	SARAH Receiver	--	--				--	--
		(b) ECM Receiver (243 mc)	--	--			--	--			BLR-1, SLR-2	*	--
8 (a) (b)	HF Voice HF Beacon	HF Homer (3-30 mc)	--	--	--	--	--	--	--	--	--	--	
9	Minitrack Beacon	(a) VHF Homer	ARN-14	ARA-8	--		--	--	--	--	--	--	--
		(b) ECM Receiver	--	--			--	--			BLR-1,SLR-2	*	
10 (a) (b) (c)	Smoke Dye Marker Reflected Sunlight	Eyeball											
11	Flashing Light	(a) Eyeball (b) IR Detector											
12	SOFAR Bomb	(a) Sonobuoy Receiver (b) MILS (c) SOFAR Net	--	--			--	--					
13	Miscellaneous	(a) Searchlight (b) Sonar	--	--	--		-- AQS-4C,-4D (in HSS only)	--					
	Reference for installed equipment		71,83	71	71	71	65	61			79	79	79

* Include also items under DD.

TABLE 7

CHARACTERISTICS OF SHIPBOARD AND AIRBORNE RADARS CONSIDERED FOR LOCAL DETECTION OF THE MERCURY CAPSULE

Radar		FPS-16	Mod II SCR-584	APS-20B,E	APS-31,A,D	APS-33B	APS-38(A)	APS-42	APS-44,A
Use		Long range detection & tracking	Long range detection	Airborne search	Airborne search	Airborne search	Airborne search	Airborne search	Airborne search
Vehicle used on		Land	Land	P2V,WV-2, ZPG-2W	UF-1,2 SA-16	P2V-6	S2F-1 ZS2G-1	SC-54	P5M-1,2
Ref. Source - Radar Data		55	55	Handbook & MIL-R-6993A	Handbook & MIL-R-6103A	Handbook	MIL-R-8586B	Handbook	Handbook
Frequency (mc)		5450-5825	2700-2900	2880 ± 30	9375 ± 55	9375 ± 55	9375 ± 55	9375 ± 55	9375 ± 55 5280 ± 30
Peak Power		1 MW-Fixed 250 KW	250-400 KW	2 MW	52 KW	52 KW	50 KW	52 KW	480 KW(x) 1 MW (c)
Rep. Rate (PPS)		(12) 341 to 1707 PPS	(14) 205 to 1707 PPS	300,900	800,200, 400	800,200, 400	800,200, 400	800,200, 400	270 PPS
Pulse Width (μs)		1/4, 1/2, 1	.8	2, 0.67	.5, 4.5, 2.5	.5, 4.5, 2.5	.5, 4.5, 2.5	.5, 4.5, 2.5	.5, 3.2
Receiver Noise Figure Receiver Band Width		11 db (2, 8 mc)	11 db (3.5 mc)	8-9 db (1.2 mc)	13 db (1.25 mc)	13 db	13 db (1.5 mc)	13 db (1.5 mc)	14 db(x) 13 db(c)
Antenna Gain		44 db	37 db	30 db	34 db	35 db	35 db	34 db	40 db(x) 34.3 db(c)
Antenna Beamwidth	Hor.	1.2°	2.8°	3.5°	±3°		±1.2°	±3°	1.8°(x)
	Vert.			8.5°	5-25° csc^2		±1.8°	5-25° csc^2	3.2°(c)
Scan Rate (RPM)	Az.			2.4 - 6			20 - 28		3, 6, 12
	Vert.			6 - 15			6 - 10		6, 12, 24
Accuracy:	Az.°	±.0/MIL	.5 - 1 MIL	±2°					
	Elev.°	±.01/MIL							
	Range (Yds.)	1.5 Yds.	15 - 40	±2%					

TABLE 8

RANGES FOR VARIOUS CAPSULE DETECTION SYSTEMS

All Ranges in Nautical Miles

Designation	Detectable Feature	Detection Means	S2F-1	P5M-1 -2 x	P5M-1 -2 c	P2V- (APS-20B,E)	WV-2	UF-1 -2	ZPG-2W	ZS2G-1	SC-54	SA-16	SH-19
1	Radar Reflection (a) Skin (b) Skin + Drogue (c) Skin + Chaff (d) As Snorkel (4)	Active Radar	20 21 36 18	54 57 92 49	46 54 103 43	42 58 122 49	42 58 122 49	20 21 37 18	42 58 122 49	20 21 36 18	20 21 37 18	20 21 37 18	-- -- -- --
2	C-Band Beacon	(a) Passive Radar (b) ECM Receiver	-- 16	-- 16	--	-- 16	-- 16	-- --	-- 16	-- 16	-- --	-- --	--
3	S-Band Beacon	(a) Passive Radar (3) (b) ECM Receiver	-- 29	-- 29		660 29	660 29	-- --	660 29	-- 29	-- --	-- --	-- --
4	UHF Voice	(a) UHF Homer (1) (b) ECM Receiver	37/52 --	37/52 87/123		37/52 87/123	37/52 87/123	37/52 --	37/52 87/123	-- 87/123	37/52 --	37/52 --	37/52 --
5	UHF Beacon/Voice	(a) UHF Homer (1) (b) ECM Receiver	18/26 --	18/26 43/62		18/26 43/62	18/26 43/62	18/26 --	18/26 43/62	-- 43/62	18/26 --	18/26 --	18/26 --
6	Telemeter	(a) UHF Homer (1) (b) ECM Receiver	42/67 --	42/67 121/193		42/67 121/193	42/67 121/193	42/67 --	42/67 121/193	-- 121/193	42/67 --	42/67 --	42/67 --
7	SARAH Beacon	(a) SARAH Receiver (5) (b) ECM Receiver	-- --	-- 412		-- 412	-- 412	-- --	-- 412	-- 412	(70) --	(70) --	-- --
8	(a) HF Voice (b) HF Beacon	HF Homer	-- --	-- --		-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --
9	Minitrack Beacon	(a) VHF Homer (b) ECM Receiver	-- --	-- 53		-- 53	-- 53	<10 --	-- 53	-- 53	<10 --	<10 --	

NOTES: 1 Two ranges separated by (/) represent range with the biconical horn antenna (BH) and the descent recovery antenna (D/R) respectively.
2 "Yes" indicates range to be determined.
3 Assumes free-running beacon transmits on a receivable/reference.
4 Snorkel range is for zero sea state.
5 SARAH on ARS aircraft is experimental.

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frequency (Km cps)	cross section (m^2)
1.3	0.08
2.9	0.4
5.5	1.4
9.4	4.1

The metalized drogue parachute was assumed to have a cross section of $1.3m^2$ based upon half a spherical reflector of 6 feet diameter (Ref. 59). Openings in the drogue and variations in viewing aspects were neglected, and it was assumed that during the period of drogue deployment, skin and chute cross sections will be additive.

According to Ref. 59 , the chaff is specified by MIL-R-5253 and 58WCLG-1877. By whatever dispensing means is used, it is assumed that 600 ft^2 ($56m^2$) of echo area result within a matter of seconds and that the effect lasts for several minutes before dispersal by wind.

K = Boltzmann's constant = 1.38×10^{-23} watt sec/deg Kelvin.

T = Absolute temperature in degrees Kelvin (taken as 300).

τ = Pulse width in seconds.

N_f = Noise figure of the receiver (dimensionless).

S = Integration factor (dimensionless). Integration factor involves the improvement in detection by adding returns from successive hits in the same scan. In estimating ranges, the following assumptions were made: a loss of 6 db to cover antenna beam shape, lack of operator alertness, non-optimized scope sweep speed. Non-optimum bandwidth and an integration factor for 50% probability of detection with a given number of hits per scan,were treated according to Ref. 54. The cumulative probability of detection for a given number of scans is plotted in Figure 10. The number of scans depends upon operating conditions: early warning, horizon limitations, etc.

Certain types of aircraft have antennas mounted underneath, and cannot see much above the horizontal plane of the aircraft. Also certain surface search radars cannot elevate appreciably for air search. Ranges for ship's radars have been estimated on the basis of limited data available. Different radars are aboard vessels of the same class. Assuming ships with the more powerful radars are assigned, it is estimated that 60 miles skin tracking and 160 miles chaff tracking can be achieved with destroyer type vessels.

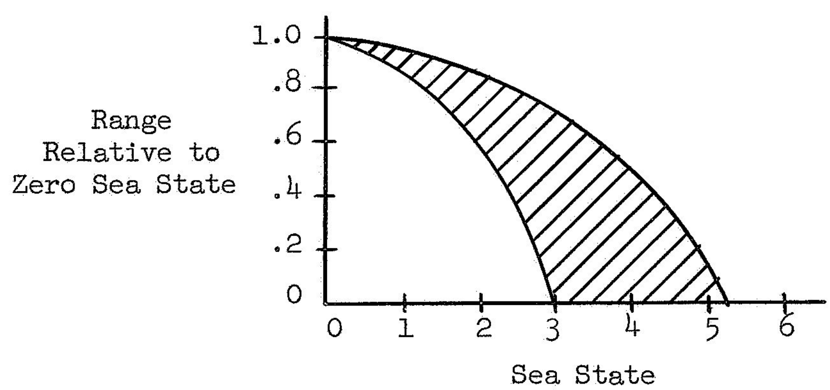
When the capsule is in the water, its free space reflectivity must be replaced by the effective skin-water reflectivity, since the water will reflect energy onto and from the capsule. However, the improvement of additional "corners" which tend to augment detection, is obscured by the large amount of water reflections (clutter) in the neighborhood of the true target. Hence the approach taken was to compare the capsule with a typical snorkel and to find the detection capability of various radars against a typical snorkel.

Reference 56 lists "sweep widths" against snorkel targets for three types of ASW radars, indicating effects of sea state and altitude. Reference 57 defines "sweep width" as the width of a band centered about the radar which contains the same number of targets as the radar, on the average, detects regardless of the lateral ranges at which the detection occurs. It is, therefore, a measure of detection probability. In fact, at a range corresponding to half the sweep width, the probability of detections of a snorkel type target is 50% or better.

The projected lateral area of the capsule in the water has been compared to that of a snorkel. The resulting ratio of two to one represents a range improvement of 18% for the capsule. Other, more tenuous factors exist (i.e., the fact that snorkels are purposely designed to be difficult to detect), but they are assumed to cancel or be negligible.

The ranges given in Table 8 are those for zero sea state.

The effect of sea state on range varies widely with weather and radar type as shown by the spread in the sketch below:



It is difficult to draw conclusions from the ranges on the capsule as an airborne and water-based target.

Passive Radar

It appears that very effective ranges are possible by receiving the C- and S-band beacons by radar. Since the radar acts passively and no synchronization between radar and beacon transmissions is assumed, only angular information is obtained and no pulse-to-pulse integration exists as beacon signals would be distributed on the display along the azimuth to the capsule.

Passive radar detection is possible only with a radar whose receiver can be tuned to the beacon's transmitting frequency. According to Reference 60, the C- and S-band beacons for the "Big Joe" shots will transmit at 5555 Mc and 2940 Mc respectively. These frequencies are too high for reception by C- and S-band radars in the aircraft under consideration but not for shipboard

radars. In fact the FPS-16 band is incompatible with the only C-band airborne radar considered. The APS-20 S-band radar has beacon receiving channels on 2820 Mc and 2880 Mc. (Reference 80). In calculating range for beacon reception on S-band, it was assumed that the beacon transmitter would be compatible with receiving radars, that the beacon's repetition rate would correspond to the Mod. II radar and that attenuation at 50% humidity and 70°F sea level conditions would not exist for more than 200 miles of radar range. The effect of no pulse-to-pulse integration for 50% detection probability was included in the range calculations.

It is presumed that after drogue parachute deployment, the capsule will have essentially a vertical descent, and that range as determined by the Mod. II's will no longer change. If the capsule at this point is greater than 300 miles from the nearest Mod. II, no triggering will occur and the beacon will no longer serve as a detectable device. Therefore, battery capacity permitting, it is recommended that the S-band beacon become free-running from drogue deployment to impact and possibly after. (Flotation bags should keep the antennas clear of the water). It is further recommended, in the event that a special code is used for interrogation, that after drogue deployment, the interrogation requirements be changed to be compatible with AN/APS-20, to permit ranging at distances far exceeding those available from chaff.

ECM Receiving and Homing

ECM receiving equipment serves the general purpose of detecting, analyzing and homing on the electromagnetic radiations of radar and radio type equipment. As an aid to Mercury recovery, the capability of ECM type equipment against the radiations of the capsule was examined.

Airborne ECM receivers cover the RF spectrum in two sections, generally: 50 to 1000 Mc and 1000 to 10,750 Mc. AN/ALR-5 and AN/ALR-3 have wide open, crystal-type receivers and each uses four antennas to cover its respective frequency section. AN/APR-13 and AN/APR-9 have tuneable superheterodyne receivers and utilize respectively five and four R-F tuners to cover the low and high sections. Direction finder group AN/APA-69 provides a rotatable antenna system and indicator for the latter pair of ECM receivers. AN/ALR-8 is a combination of APR-13 and APR-9.

Characteristics of the above units are given in Table 9.
The effectiveness of these ECM receivers to home on the Mercury radiations was calculated using equation (2).

$$R^2 \quad 10^{.1 \propto R 10^{-3}} = \frac{P_T\ G_T\ G_R\ \lambda^2}{(4\pi)^2\ P_R} \qquad \text{Equation (2)}$$

where R = range in meters

α = attenuation in decibels per kilometer, making the same assumptions as for active radar at C- and S-band and neglecting α at UHF and VHF.

P_T = power transmitted by the Mercury transmitter in watts.

G_T = gain of the Mercury transmitting antenna (dimensionless).

G_R = gain of the recovery vehicle receiving antenna (dimensionless).

λ = wavelength in meters.

P_R = required received power in watts for the minimum signal to noise ratio for detection.

The resulting ranges listed in Table 8 are not necessarily those for 50% probability of detection, but those which yield the minimum detectable signal.

In calculating ranges, it was assumed that the peak signal would be detectable in the case of pulsed emissions. Calculations are based on APR-9 and -13 data since these are more sensitive than ALR-3 and -5.

Since the frequencies of the capsule will be known, it will not be necessary to scan in frequency. Antenna scan should be employed until information is relayed from the tracking network in what direction to expect the capsule; then manual sector search should be used until a signal is found. The strongest anticipated signal should be sought first. The only need for changing frequency should be in the event that the strongest signal is absent.

Details on shipboard ECM equipment were not available during the study, but BuShips personnel (Ref. 61) indicate that shipboard capability is comparable to airborne capability.

UHF Homing

The standard airborne UHF homer is AN/ARA-25. It operates in connection with a UHF receiver such as AN/ARC-27 or AN/ARC-52.

Tests made at Grumman,(References 75 and 76) on the ARA-25 installation in the UF-1 and F9F-8P aircraft indicate that homing can be accomplished at 110 nautical miles against an ARC-27 transmitter (9 watts output, 2 db antenna). Ranges for homing on the capsule's UHF radiations (voice, beacon/voice and telemeter) were obtained by appropriate ratio using equation (2) with $\alpha = 0$.

The shipboard UHF homer, AN/URD-4, is said to be equivalent to ARA-25. It is generally available on destroyer type vessels.

TABLE 9

CHARACTERISTICS OF AIRBORNE ECM RECEIVER-DIRECTION FINDERS

Receiver Nomenclature	AN/ALR-3	AN/ALR-5	AN/APR-13	AN/APR-9	AN/ALR-8	AN/BLR-1	AN/SLR-2
Frequency range showing tuning bands (in Mcps)	A: 1000-2600 B: 2300-4450 C: 4300-7350 D: 7050-10750	A: 38-135 B: 125-300 C: 290-550 D: 530-1000	A: 50-100 B: 90-180 C: 160-320 D: 300-600 E: 550-1100	A: 1000-2600 B: 2300-4450 C: 4300-7350 D: 7050-10750	Combination of APR-13 and APR-8	90 to 10750 in 8 bands	90 to 10750 in 8 bands
Sensitivity	10 microvolts from 50 ohm source for 3 db gain over noise	10 microvolts from 50 ohm source for 3 db gain over noise on all bands	A: 100 dbm B,C: 97 dbm D,E: 90 dbm	A,B,C,D: 80 dbm			
Receiver Type	Wide open	Wide open	Super Heterodyne	Super Heterodyne			
Receiver Reference	68	69	72, 73	72, 73	72, 73	80	80
Antenna System	Part of ALR-3		APA-69	APA-69	APA-69		
Antenna Characteristic	50° beamwidth to half power points in each of bands A thru D		140-1500 mc, ±5° accuracy, -3 db gain	1000-5000 mc, ±3°, 3 db; 4000-12000 mc, ±5°, 7 db	See APR-13 and APR-8		
Antenna Reference	68		74	74	74		

The ARA-25 is not capable of homing on the SARAH beacon because of its low (200 cps) repetition rate. If the frequency is increased to 500 cps or more, then it is reported (Ref. 71) that ARA-25 homing is possible.

SARAH Receiver

The SARAH beacon is intended for use with a SARAH receiver and appropriate two-lobe antenna. According to Reference 77 , the SARAH system is capable of 70 miles range subject to horizon limitations. For ships having antenna heights of 30 or 40 feet, the range is about 6 miles. A null in the antenna pattern permits location of the transmitter to within ±100 feet by an aircraft flying over the transmitter at 500 feet. The only aircraft believed to have SARAH receivers as permanently installed equipment are the JC-54's at AMR. The Air Rescue Service is experimenting with two SARAH receivers (Reference 71).

H.F. Homer

H.F. homing devices are not carried on ships and aircraft. Shore based high frequency direction finders are operated by the military services and FCC. The Navy HF/DF network uses AN/GRD-6 which receives amplitude modulated signals from 2 to 32 Mc (Reference 61). The National Search and Rescue Manual (Reference 18) states that fixes from the HF/DF nets are available within 10 minutes. The 8.364 Mc SEASAVE frequency is a standard SAR frequency for life boat, life raft and survival craft and should be regularly monitored. The HF voice frequency is also within the HF/DF net's frequency band. Procedure for using the voice transmitter as a distress call is given in Reference 18.

Acoustic Detection

Destroyer type ships and some helicopters and lighter than aircraft have sonar sets for acoustic echo ranging on objects below the surface. Ranges of sonar against large ships is of the order of 10 to 20 miles. Since the Mercury capsule has such a small underwater surface, it is estimated that sonar ranges would be vanishingly small.

Sonar can be used passively as a means of ranging. However, it is expected that the only significant sound generated by the Mercury capsule will come from SOFAR bombs designed to explode at considerable depth to take advantage of known sound channels. The only sound expected to reach the surface is in the immediate vicinity of the capsule. Directional sound receiving heads which can be lowered to several thousand feet should be useful.

Sonobuoys are non-directional listening devices which pick up sounds in the water and relay them to sonobuoy receivers in aircraft. From the geometry of sonobuoys and aircraft, location of sound sources can be determined by timing corresponding signals from several buoys. Since the SOFAR bombs are expected to explode in a deep sound channel, conventional sonobuoys which

listen near the surface are useful only in the immediate vicinity of the capsule. Deep listening sonobuoys are known to be under test. If such are available at the time of Mercury's test, the sonobuoy system should provide an additional means of detection and homing. Effective ranges are believed to be restricted by line-of-sight transmission, buoy-laying capability of the aircraft involved and battery life of the buoy.

The shore based SOFAR listening network and the MILS network are believed to be effective with SOFAR bombs, but security restrictions have prevented any estimates of its effective area of coverage.

VHF Homing

VHF homing is accomplished in a limited number of aircraft by AN/ARA-8 in conjunction with a VHF receiver as AN/ARC-1. A major difficulty in evaluating the usefulness of homing on the minitrack beacon (108 Mc) is that ARA-8 is designed for operation between 120 and 140 Mc, although the required receiver has capability down to 100 Mc. No specification or test data have been found at 108 Mc.

It is noted that tests made at Grumman indicate that homing on VHF transmitters using the ARA-25 homer with appropriate VHF receivers is effective. The modification to connect the VHF receiver to the ARA-25 is a simple field change.

However, because of the very low power of the minitrack beacon, it is estimated that ranges of less than 10 miles will result.

Miscellaneous

Certain other devices may be of value in detecting the capsule. In the event that impact occurs in darkness or the search continues past sunset, some aircraft, as listed in Table 6 , have searchlights to help pinpoint the capsule when other homing devices have brought them to the vicinity of the capsule.

It has been reported (Reference 71) that ACR Electronics, 551 West 22nd Street, New York City, has under test an automatic infrared homing device capable of detecting flashing light beacons at ranges equal to or greater than eyeball detection. It is mentioned here as a possible means of increasing detection probability on the flashing light to be carried by the capsule.

Anti-collision lights are carried aboard all aircraft. Under the proper viewing conditions they may be visible up to 15 or 20 miles. Blue white strobe light, such as the Atkins Relative Danger Light (Reference 78), although not yet approved as a standard warning light, is reported to be visible at $2\frac{1}{2}$ to 3 times the distance. Such a light has been demonstrated to be distinguishable at 50 miles or more. The Mercury astronaut, if he

were able to open the capsule, might sight a searching aircraft carrying a strobe light before it sighted him, particularly if the electronic devices in the capsule had failed. Equipped with a compass and a battery-powered radio, he could then direct the aircraft by radio.

Communication Equipment

Later, when most appropriate , the requirements and capabilities of the means of communicating between and among the tracking and ground instrumentation system, the recovery forces and the capsule are considered. Characteristics of the capsule's communication equipment have already been described . In this section applicable communication equipments of the recovery vehicles are tabulated and described. Tables 11 and 12 contain listings of airborne and shipboard communications equipment respectively, divided into frequency bands. These are high frequency (HF - 2 to 36 Mc), very high frequency (VHF - 100 to 156 Mc) and ultra high frequency (UHF - 225 to 400 Mc). HF radio signals can travel over the horizon by ground wave (short range) and sky wave (long range). VHF and UHF signals are limited to line-of-sight.

Calculations of ranges of communication capability are by means of equation (3),

$$R^2 = \frac{P_T G_T G_R \lambda^2}{(4\pi)^2 P_R} \qquad (3)$$

where the symbols are defined under equation (2). The range derived from equation (3) represents maximum possible range. It does not account for propagation losses or equipment losses nor does it consider horizon limitations. Maximum ranges for communication from the capsule to typical aircraft receivers are given in Table 13; the values are based on the characteristics of Table 10. Ranges for other communication links are also discussed in that section.

Table 10

Characteristics of Receivers Used to Calculate Ranges of Table

	ARC-27	ARC-38
Receiver Sensitivity	5 microvolts into 50 ohms provides 6 db phone signal to noise ratio.	5 microvolts into 50 ohms provides 6 db phone signal to noise ratio.
Antenna Gain	dipole = 2 db	Assumed unity gain. Varies with size of aircraft.
Reference for Receiver	81	82

TABLE 11

AIRCRAFT COMMUNICATIONS AND NAVIGATION EQUIPMENT

	S2F-1	P5M-1 -2	P2V-5F -6 -7	WV-2	UF-1 -2	ZPG-2	ZPG-2W	ZS2G-1	SC-54	SA-16	SH-19	SH-21	JC-54	HR2S-1	HUS-1 HSS-1 -1N
UHF Transmitter-Receiver 225-400 mc (1)	ARC-27A	ARC-27A	ARC-27(A)	ARC-27	ARC-27	ARC-27(A)	ARC-27	ARC-27A	ARC-27	ARC-27	ARC-27	ARC-27		ARC-55 or ARC-27A	ARC-27 or ARC-55
VHF Transmitter-Receiver 100-156 mc	--	ARC-1(A)	ARC-1(A)	ARC-1(A)	ARC-1(A) (in - 1 only)	ARC-1(A)	--	--	ARC-3	ARC-3	ARC-1				--
HF Transmitter-Receiver (2) 2-9.05 mc	ARC-2(A)				ARC-2(A) (in - 1)			ARR-15A (1.5-18.5 mc) and ART-13		--				ARC-2(A)	ARC-2(A)
HF Transmitter-Receiver (2) 2-25 mc	--	ARC-38	ARC-38	ARC-37 (2-36 mc)	ARC-38 (in - 2)	ARC-38	ARC-38	(2-15 mc and .2 to 1.5 mc)		--					
Loran Receiver	--	APN-4 or APN-70	APN-4 or APN-70	APN-70	APN-4 or APN-70	APN-4 or APN-70	APN-70	APN-70		APN-4 -9 -70				--	--
TACAN Receiver	ARN-21A	ARN-21	ARN-21	ARN-21	ARN-21(A)	--	--	--	Yes	ARN-21(A)				ARN-21	ARN-21
Radio Compass	ARN-6	ARN-6	ARN-6	ARN-6	ARN-59	ARN-6	APN-6	ARN-6	ARN-6 or ARN-44	ARN-6				ARN-41A	ARN-41A or ARN-59
Reference	56,61,70	56,61	56,61	61	61,70	56	61	56	71	71,83	71	71		61	56,61

NOTES: 1. ARC-52 which has a more powerful transmitter and lower weight than ARC-27(A) may be installed.
2. ARC-39 may be used in place of ARC-2(A). ARR-15, ARR-41 and ART-13 have been used in some aircraft.
3. The equipment listed is based on the latest references obtainable during the brief period of the study.
4. A vacant space indicates a lack of data on that particular equipment.

TABLE 12

SHIPS COMMUNICATION AND NAVIGATION EQUIPMENT BY CLASS OF SHIPS

	DD	DDE*	AKL	AP	LSD	SS
UHF Communications	URR-13 URR-35 TDZ TED	GRC-27 ARC-27 SCR-300	TED MAR URR-13 URR-35	--	URR-13 URR-35 RDZ TDZ TED	URR-13 ARC-27 TED
HF Communications	SRR-13 RBS, TBX TBL, RBC SSB-1 TCS RAL	SRT-15	TDE, RBG TCS TCZ RAL RAO	RAL, TDE RAO RBC DCH TBK	BAL RAO, TCS RBC TBL TCZ	RAL RBS TBL TCS TCZ
Loran	DAS	DAS	DAS	SPN-7	DAS SPN-7	DAS

This tabulation, taken from Ref. (79), is not considered a complete list.

* Plus items on DD vessel type listing.

Navigation Equipment

Navigation systems such as LORAN, TACAN and radio compass are generally well known. Tables 11 and 12 list certain types of airborne and shipboard navigation equipment. A chart of the usefulness of LORAN in the North Atlantic is shown in Figure 26, which accompanies a later discussion of navigational capabilities.

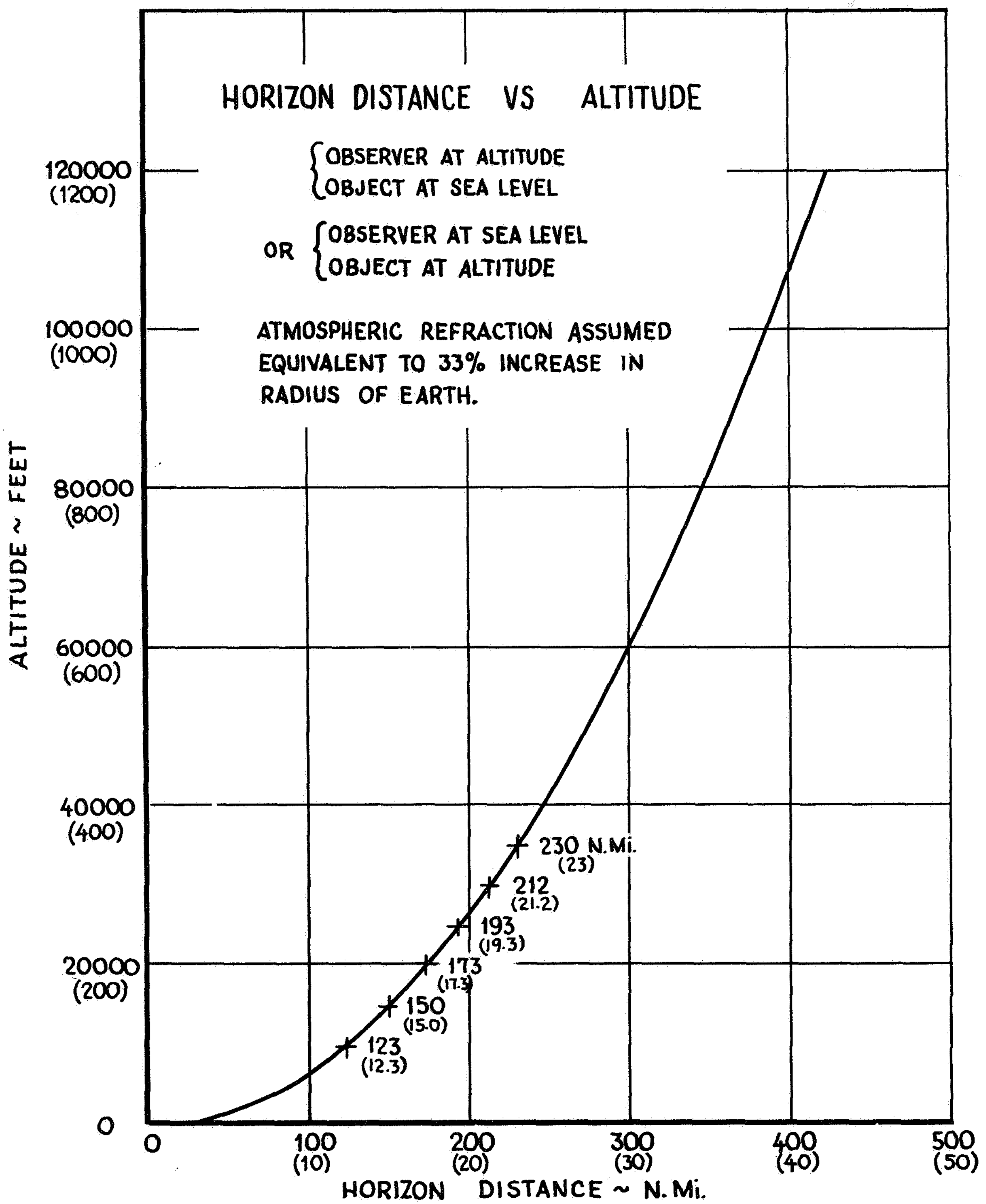


Fig. 7

LOCAL DETECTION AND TRACKING TO IMPACT

General

Before impact, the capsule travels through the following flight regimes:

* Orbital flight (except in all abort areas, where the vehicle is traveling on a path to orbit)
* Re-entry, from firing of retro-rockets to opening of drogue parachute (approximately 14 minutes).
* From opening of drogue to opening of main chute (2.4 minutes).
* From main parachute opening to water impact (5.3 minutes).

Orbital Flight

Detection and tracking while the vehicle is in orbit must be performed by the tracking and ground instrumentation system (TGIS) stations. Very few recovery area vehicles in the local recovery areas can detect it since the capsule passes over the likely impact areas rarely, and then for only a short time. Information transmitted to the local area from the TGIS stations can be employed to shrink the probable impact area, so that greater effort can be concentrated on detecting the vehicle in this smaller region.

Re-entry

When the retro-rockets fire, the vehicle travels over a long descending path, over most of which the only tracking possible is with the TGIS stations. Only the terminal portion of this path passes near or over a local area. The two most useful detection means in this flight regime are visual and radar detection. It is possible, however, that some radio or beacon homing aids would be useful despite the ionization layer which accompanies the capsule through this free flight portion of its descent. Because of radar range and altitude limitations, visual detecting may be the only method available to the local force.

Parachute Descent

If the capsule has been detected and tracked to the point where the drogue parachute opens, the uncertainty in the impact location can be reduced to a few miles, since the travel from this point along the track to the point of impact is only approximately 20 miles. The portion of the flight from opening of drogue chute to the opening of the main parachute is very short, but radar detection may be possible to aircraft within line of sight of the capsule. After the main parachute opens, and until water impact, the descent of the capsule is essentially vertical. A detection in this flight regime assures an excellent fix after impact when wind velocity effects have been taken into account. Detection in this region ensures a very short search on impact, and prompt capsule recovery.

Fig. 8

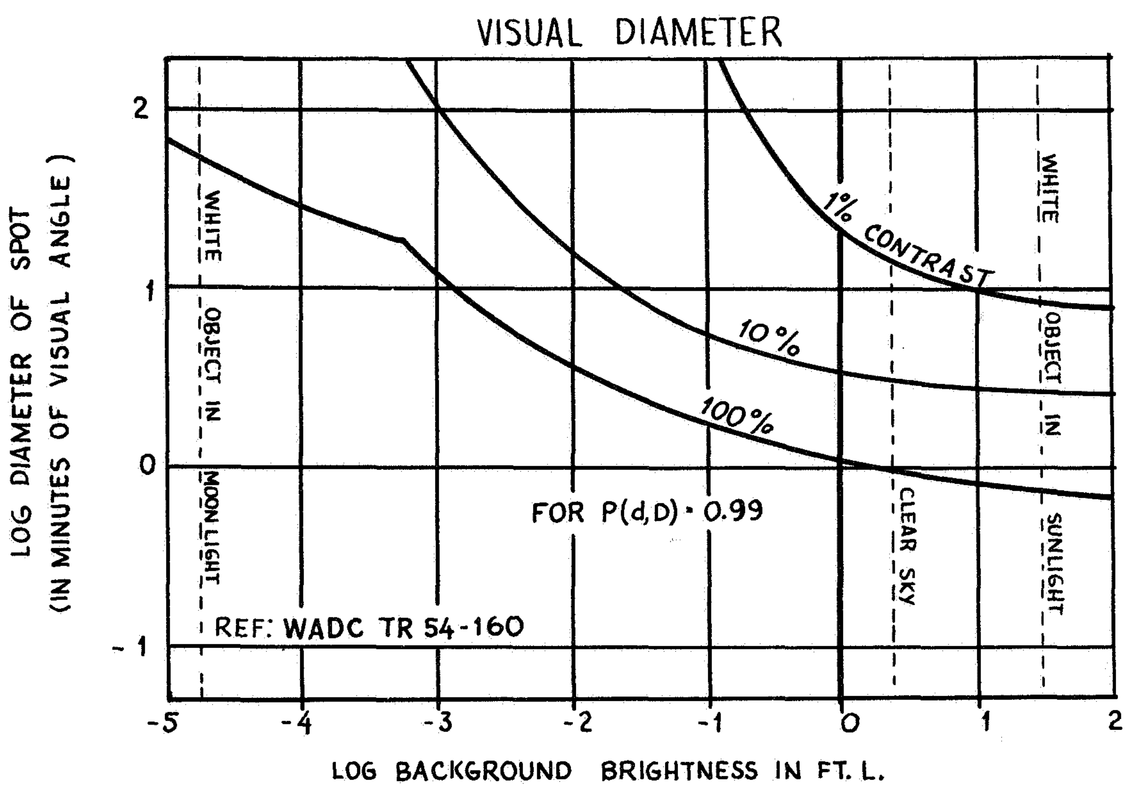
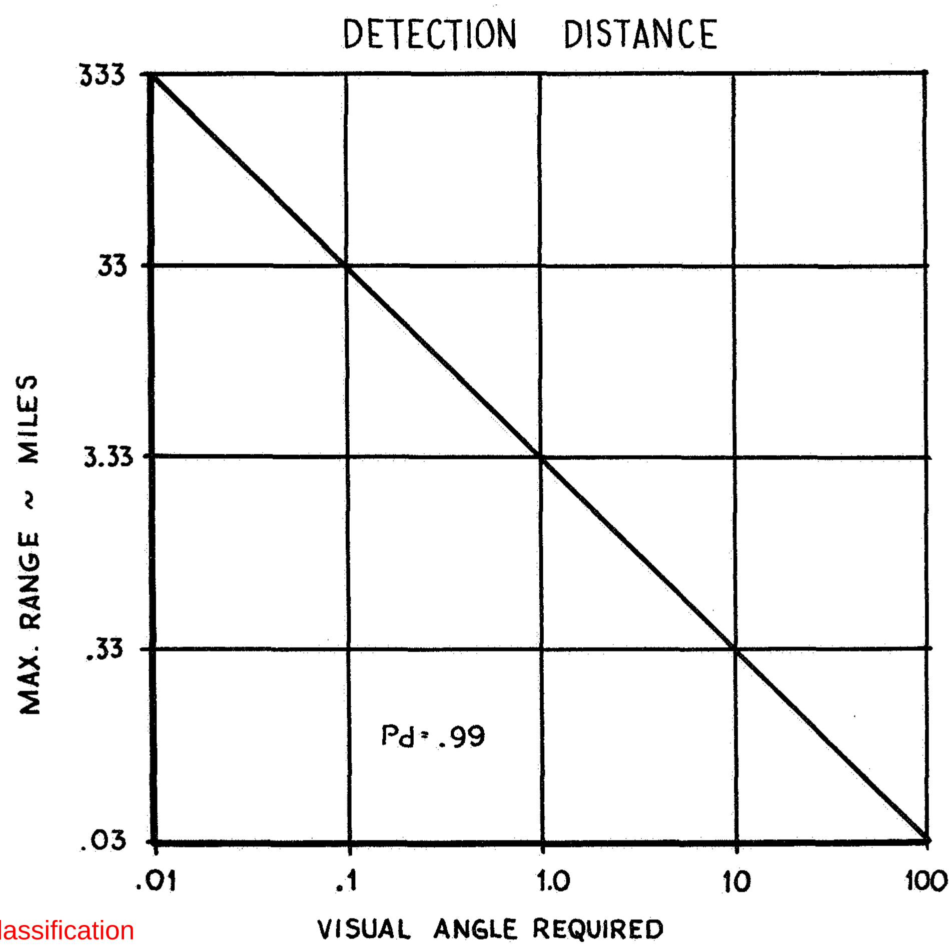

VISUAL DIAMETER
2
1
0
-1
LOG DIAMETER OF SPOT
(IN MINUTES OF VISUAL ANGLE)
WHITE OBJECT IN MOONLIGHT
WHITE OBJECT IN SUNLIGHT
CLEAR SKY
1% CONTRAST
10%
100%
FOR P(d,D) = 0.99
REF: WADC TR 54-160
-5
-4
-3
-2
-1
0
1
2
LOG BACKGROUND BRIGHTNESS IN FT. L.

Fig. 9


DETECTION DISTANCE
333
33
3.33
.33
.03
MAX. RANGE ~ MILES
Pd = .99
.01
.1
1.0
10
100
VISUAL ANGLE REQUIRED

Visual Detection

Figure 3 . shows a plot of the vehicle trajectory from retrofire to impact. This figure indicates that the expected incandescence of the capsule occurs over approximately one minute of flight time, and within approximately 50 miles of the impact point, assuming that incandescence will occur between 150,000 and 100,000 feet altitude. It will be brighter than the background stars if the descent occurs at night. Under these conditions, the vehicle will be visible to searchers for about one minute, anywhere within the capsule's horizon. Since this portion of the flight regime is generally higher than the detection limitations of most radar sets, visual detection becomes a very important aid. A detection at this point considerably reduces the size of the probable impact area, since total travel from the start of incandescence to impact is less than about 50 miles along the capsule track.

Below about 100,000 feet, the capsule cools so that the glow is extinguished. From this point, the contrast between the capsule and the sky is greatly diminished. Before an impact by day or night, this portion of the flight will represent great difficulties in visual detection. In addition to the very low contrast between the capsule and the background, there will be an element of glare from the remainder of the sky. Figure 8 ,taken from Reference 20 , indicates the visual angle required to attain a 99% probability of detection of a target against a uniform background as a function of contrast and background brightness. Typical background values have been included on this figure. Figure 9 shows the attainable ranges to the capsule as a function of visual angle required. As an example of the use of these two figures, assuming the capsule contrast with the sky is 100%, then in moonlight, the required visual angle is $10^{1.7}$ (or approximately 50) minutes of arc. The capsule presents this visual angle at about one-tenth mile from the observer.

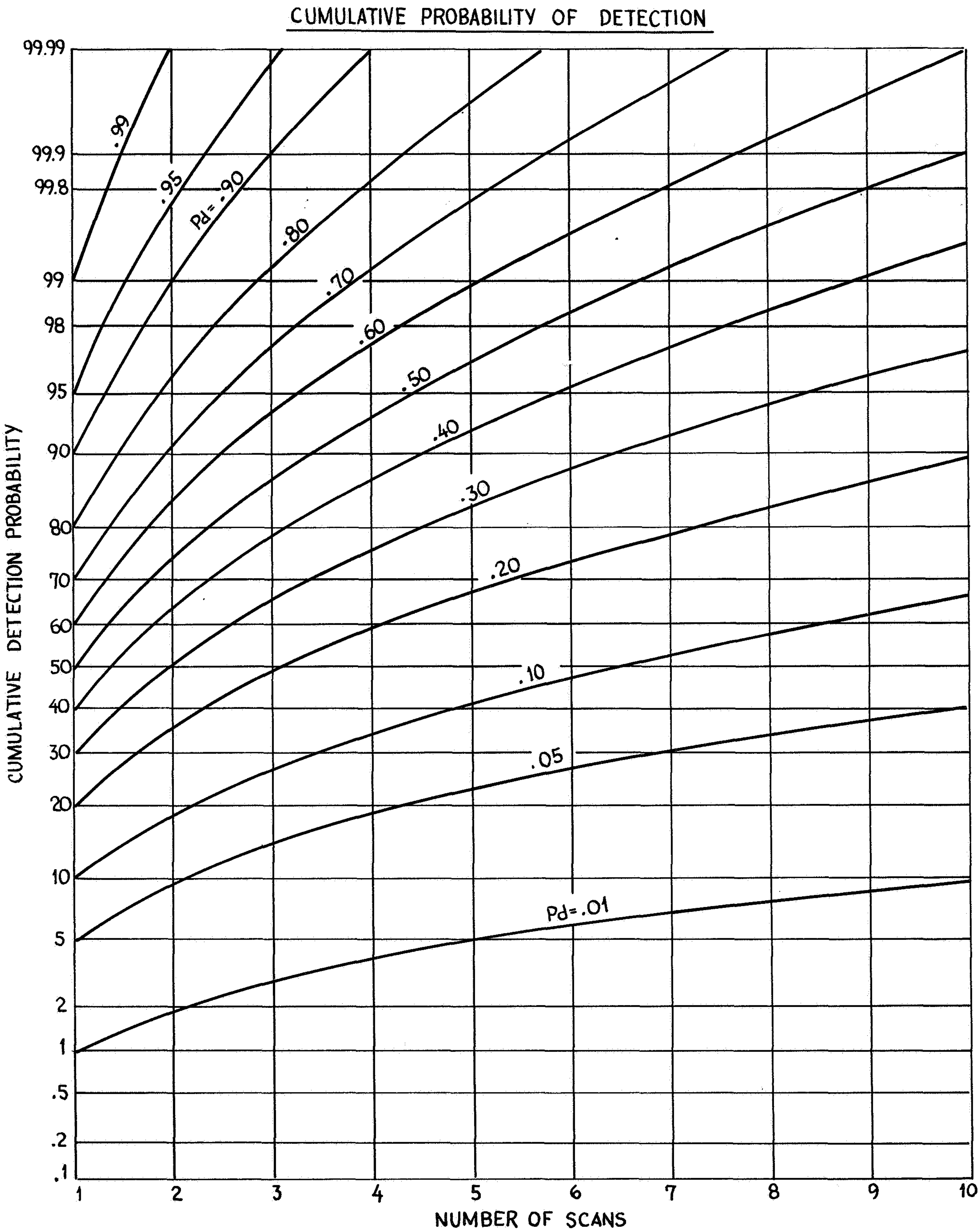
Because of the problem of glare when visually searching for the capsule before impact, and in view of the increased detection capability due to capsule incandescence, launch should be made so that the capsule impacts after sunset but before dawn, to obtain maximum detection probability.

Electronic Detection

The previous section of this report entitled "Applicable Electronic Equipment" has tabulated ranges for various equipments aboard detection vehicles. Radar ranges have been calculated for a single scan probability of detection of 0.5. The probability of detection for several scans is a function of the number of scans, and of the single scan probability. It can be stated by

$$P_{(d,n)} = 1-(1-P_d)^n$$

where: n = number of scans
$P(d,n)$ = cumulative probability of detection
P_d = single scan probability of detection



CUMULATIVE PROBABILITY OF DETECTION
CUMULATIVE DETECTION PROBABILITY
NUMBER OF SCANS
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
.5
.2
.1
1
2
3
4
5
6
7
8
9
10
.99
.95
Pd=.90
.80
.70
.60
.50
.40
.30
.20
.10
.05
Pd=.01

Fig. 10

Figure 10 shows this relationship for up to 10 scans. With this figure, and knowing the time the capsule is within line of sight, the scan rate of the electronic detection equipment and the range for 0.5 detection probability, the probability of detection can be ascertained for each piece of detection equipment at the indicated range.

SEARCH AFTER IMPACT

General

After capsule impact, its exact location must be ascertained to permit prompt recovery. If the capsule has been tracked to impact the detection problem should be relatively simple. Either the tracking aircraft has contact continuously while it proceeds to the impact area, or it is proceeding to a point within a few miles of impact position. Impact position is known less accurately when tracking to impact in the local area has been incomplete, or lacking altogether. The largest size area of uncertainty appears to be a circle of about 30 miles in radius, when all impact prediction has been done ashore and forwarded to the local area command (Reference 60).

When the capsule must be located after impact, the searching forces have three major detection methods available, namely, acoustical, visual and electronic.

Acoustical Detection

It appears that the local area forces will not be capable of utilizing underwater acoustical detection methods or equipments for search. The capsule has none of the desirable characteristics of a sonar target for active acoustical search. The target is also producing virtually no noise due to either machinery or water travel so that normal passive techniques would be ineffective. It would be difficult to alter the capsule characteristics to improve its qualities as an effective acoustic target for local area forces. In addition, the value of such an additional capability would be questionable due to the limited range and changeable nature of underwater acoustics.

However, the presently configured capsule contains explosive charges, which can indicate its location to shore tracking stations. This information can be forwarded to the local area, to aid in search. The positional accuracy attainable through this technique varies with distance from the shore stations, so information obtained through the use of this equipment varies in accuracy from approximately what the local forces can do with good descent tracking, to accuracies somewhat better than the impact predictions attainable by the satellite tracking system. This detection aid is, however, only available with the above mentioned accuracies in the final orbital impact area.

Although it is not now in the capsule, a fog horn would help provide all-weather recovery capability. Electronic aids can lead retrieving vehicles close enough for visual sighting under normal conditions, but a ship might pass within a few yards of the capsule in a thick fog without anyone detecting it unless an acoustic device were in operation. Small, compact, pre-pressurized units are available for small-boat use and might be added to the pilots survival gear.

Another acoustic device that could aid recovery, in the unlikely event that the capsule were damaged enough to sink in shallow-water, is a small sonar-type beacon. Although none are available as off-the-shelf items, such devices have been built for "laboratory" use and would be capable (with little power required) of providing a homing signal to aid a diving party to find the capsule if the general impact area were known. There is considerable shoal water off near Bermuda and in the final landing area where diving operations are practical.

Visual Detection

Visual detection has always been, and is now, the primary method for finding an object at sea. As such, it can be employed to good advantage in capsule recovery, particularly by air anti-submarine crews, and Search and Rescue personnel. The techniques have been refined through years of use, and have been standardized throughout the world.

Reference 19 gives the values of the several search parameters, and is the guiding directive for Naval operating technique. Sweep width is defined in Reference 19 as a "mathematically determined measure of detection capability that varies with method of detection, equipment employed, character of object or target being sought, search speed, and weather conditions. It is a measure that is reduced arbitrarily at the maximum range of any given sweep so that the scattered targets which may be detected beyond those limits are equal in number to the targets which may be missed within the same limits."

In this report "sweep width" is interpreted as twice the range which satisfies

$$P_d(\text{out}) = 1 - P_d(\text{in}) \qquad \text{Equation 4}$$

where:

$P_d(\text{out})$ = probability of detection of a target outside given range.

$P_d(\text{in})$ = probability of detection of a target inside given range.

If nothing about the detection probability function is assumed except that detection is at least as probable inside the given range as outside, that is

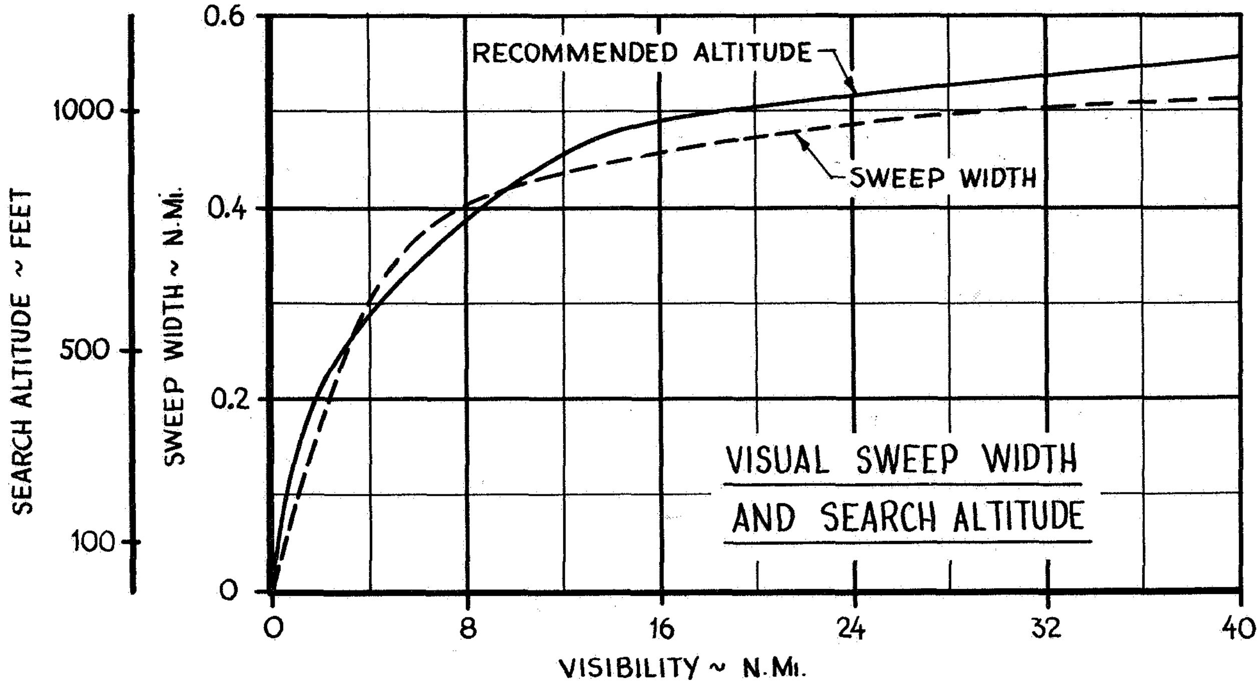
$$P_d(\text{in}) = P_d(\text{out}) \qquad \text{Equation 5}$$

then, the given range can be seen to be one at which

$$P_d(\text{in}) = 0.5 \qquad \text{Equation 6}$$

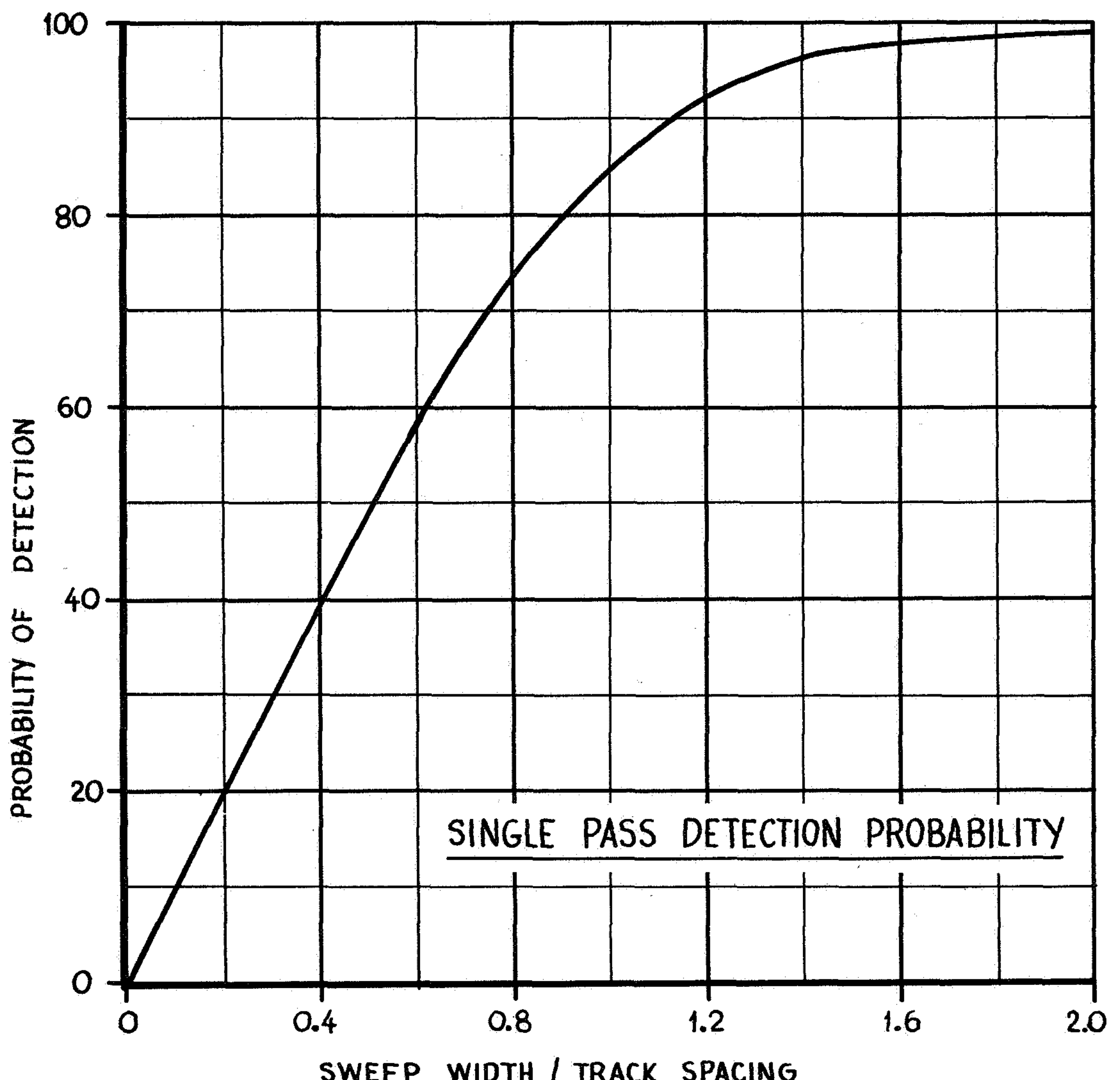
Sweep width, throughout this report, has been taken at twice the range to 0.5 probability of detection. For this purpose, the capsule without location aids has been taken as equivalent to a one man raft. Sweep widths attainable with various aids are tabulated later in this section. Figure 11 shows values extracted from Reference 19 for visual sweep width and recommended search

Fig. 11



SEARCH ALTITUDE ~ FEET
1000
500
100
SWEEP WIDTH ~ N.Mi.
0.6
0.4
0.2
0
RECOMMENDED ALTITUDE
SWEEP WIDTH
VISUAL SWEEP WIDTH
AND SEARCH ALTITUDE
0
8
16
24
32
40
VISIBILITY ~ N.Mi.

Fig. 12



PROBABILITY OF DETECTION
100
80
60
40
20
0
SINGLE PASS DETECTION PROBABILITY
0
0.4
0.8
1.2
1.6
2.0
SWEEP WIDTH / TRACK SPACING

altitude, for air-to-surface search for the capsule. Generally, this figure shows that search altitude should be approximately 1000 feet, and that attainable sweep width is approximately one half mile. Search altitudes may be changed slightly to conform to requirements for electronic detection means, without too great a degradation in reasonable visibilities. This point will be discussed later in this section.

Figure 12 shows single-pass probability of detection as a function of sweep width and track spacing for search throughout an uncertainty area. Single-pass probability is the probability of detection when the area is searched only once. Subsequent searches increase the overall detection probability. This figure shows that single-pass probability of detection can be varied by changing search track spacing. Since a change in track spacing implies a change in time required to search once through the uncertainty area, and since probability of detection is enhanced by multiple searches in an area, the question arises as to whether there is a minimum search time to attain a given probability of detection. To answer this properly, the relation between search time (t), track spacing (S) and sweep width (W) must be developed. Figure 13 shows a diagram of a parallel sweep search of a square area of size "A". In this figure, the search vehicle begins its search in the upper left hand corner of the area, spaced one half track spacing from each side forming that corner. The vehicle proceeds parallel to one side of the area until one half track spacing from the bounding edge on the right, then turns, proceeds parallel to this edge a distance equal to track spacing, turns again and proceeds parallel to the original course. This procedure is continued until the entire area is searched. It is clear that the length of the first search leg is $A^{\frac{1}{2}} - S$, while that of the leg perpendicular to this is S. The aircraft searching this square area flies a distance expressed as:

$$d = (A^{\frac{1}{2}} - S)\left(\frac{A^{\frac{1}{2}}}{S}\right) + \left(\frac{A^{\frac{1}{2}}}{S} - 1\right) S$$

$$= \frac{A}{S} - S \qquad \text{Equation 7}$$

Time, of course, is

$$t = \frac{d}{V_s} \qquad \text{Equation 8}$$

Probability of detection on subsequent searches, when the single search probability is known, can be represented, grossly, by:

$$P_{d,n} = 1 - (1 - P_{d,1})^n$$

where: $P_{d,1}$ = single-pass detection probability

$P_{d,n}$ = detection probability over n passes

Fig. 13

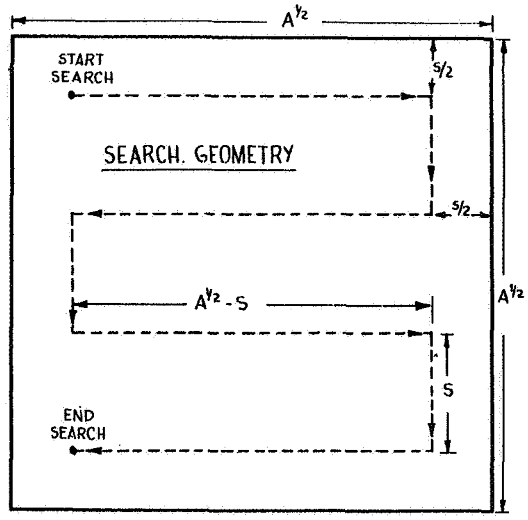


Fig. 14

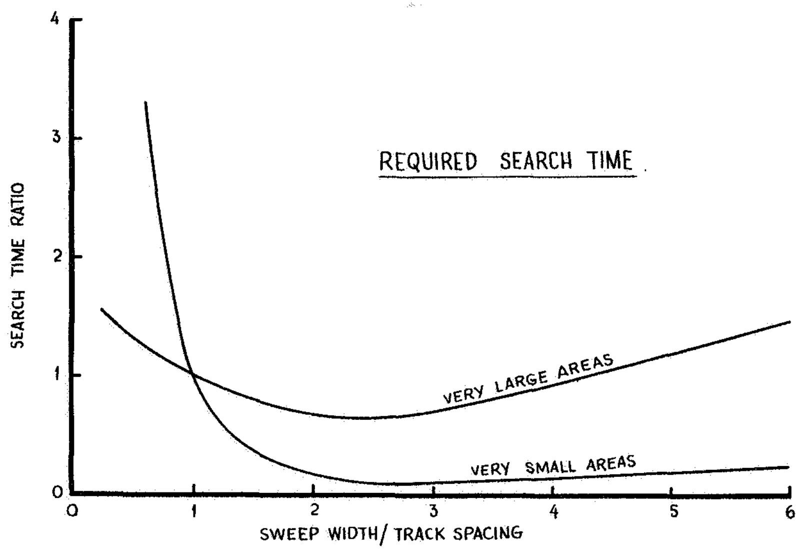
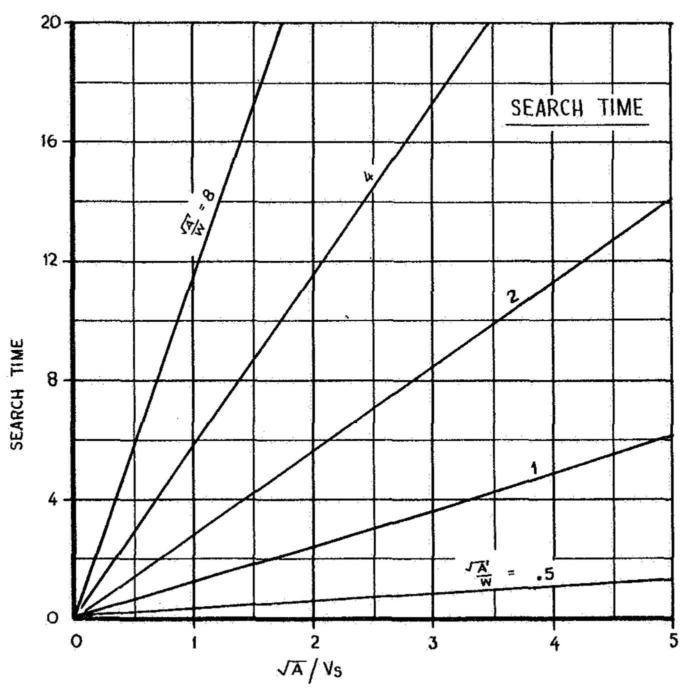


Fig. 15



n = number of searches through area

so that: $$n = \frac{\ln (1 - Pd,n)}{\ln (1 - Pd,1)} \qquad \text{Equation 9}$$

Total search time to attain a given probability of detection is, then,

$$t = \frac{n}{Vs}\left(\frac{A}{S} - S\right) = \frac{(A - S^2)\ \ln (1 - Pd,n)}{(SVs)\ \ln (1 - Pd,1)} \qquad \text{Equation 10}$$

If sweep width is taken equal to track spacing and desired detection probability is 0.99, then equation 10 reduces to

$$t_o = \frac{(A-W^2)}{WVs} \cdot \frac{-2}{\log(.15)} = 2.42\ \frac{(A-W^2)}{WVs}$$

Taking this time as the standard, then the ratio of search time to this standard time is

$$t/t_o = \frac{\dfrac{-2\ (A-S^2)}{\log(1-Pd,1)\ SVs}}{2.42\ \dfrac{(A-W^2)}{WVs}} = \frac{-.824}{\log(1-Pd,1)}\ \frac{A-S^2}{A-W^2} \cdot \frac{W}{S} \qquad \text{Equation 11}$$

where Pd,1 is obtained from Figure 12 as a function of W/S. Examination of equation 11 shows that as area increases the time ratio approaches W/S times the constant term (in brackets), while as area decreases, the time ratio approaches S/W times the same constant term.

Figure 14 shows this relationship for the probability function shown in Figure 12 , where time is relative to the time required to perform the same search with sweep width equal to track spacing. A final probability level of .99 has been chosen in presenting these data. This figure shows that for most areas, a minimum occurs at a spacing ratio of approximately 2.5, that is, at track spacing about 0.4 times the sweep width. If this track spacing is employed, equation 10 reduces to:

$$t = \frac{(A - S^2)}{(S\ Vs)} \cdot \frac{(-2)}{(-3.4)}$$

$$= 1.47\ \frac{A}{WVs} - .24\ \frac{W}{Vs} \qquad \text{Equation 12}$$

As W approaches $A^{\frac{1}{2}}$, that is, as the sweep width covers an entire side of the search area, equation 12 reduces to:

$$t = 1.23 \frac{A^{\frac{1}{2}}}{Vs} \qquad \text{Equation 13}$$

showing that the aircraft needs slightly more than one sweep through the uncertainty area to assure a detection probability of .99. As W becomes very small compared to $A^{\frac{1}{2}}$, equation 12 reduces to:

$$t = 1.47 \frac{A}{W\ Vs} \qquad \text{Equation 14}$$

suggesting that approximately two trips through the uncertainty area are required to attain the desired detection probability. As W increases beyond $A^{\frac{1}{2}}$, t approaches zero, indicating that one look at the area is sufficient in this case. This latest case and the case exemplified by equation 13 are typical of aircraft employing electromagnetic search systems of reasonably long range capabilities. The case shown in equation 14 is reasonable for aircraft and ships searching visually in large uncertainty areas. Figure 15 shows t as a function of $\frac{A^{\frac{1}{2}}}{Vs}$ for some values of $\frac{A^{\frac{1}{2}}}{W}$.

Visual Aids

Previously in this section, visual sweep width was seen to vary with visibility, and to average, for the capsule, about 0.4 to 0.5 miles. The following table gives average values for detection range when various visual aids are incorporated in the capsule:

Visual Aid	Approximate Detection Range	Remarks
Dye Markers	One to ten miles. At search altitude, approximately three miles.	Remains visible up to 2 hours in calm sea, but dissipates rapidly in rough water.
Flash-Light (2 Cell)	Zero to 11 miles. Maximum when beam up toward observer.	Personal item. Night-time use.
Smoke	About 10 miles.	Dependent very strongly on wind velocity near surface.
Capsule Flashing Light	Up to about 50 miles.	Night time use.
Mirror	Visible to horizon.	Limited by haze. Daytime use.

Use of the aids listed on the previous page results in higher detection probabilities, for a given track spacing. Employing the results obtained as shown in Figure 15, it can be seen that their use can materially reduce search time for a given desired level of detection probability.

Electronic Detection

Table 8 lists the ranges attainable when searching for the capsule using various electronic equipments listed. These ranges are for detection probability equal to 0.5 per scan, and therefore are considered to be half the sweep width of the equipment and of the vehicles carrying those equipments. The previous discussion in this section concerning sweep width, track spacing and detection probability, applies equally to electronic equipment. Since the ranges attainable with this equipment are larger, by orders of magnitude, than those attainable employing visual search, search altitude should be that which optimizes probability of detection with the electronic detection equipment.

Application to Search in Practice

There are a number of established procedures for performing a search, based on experience of all the military services and other sea-going and air agencies in general, and by the U.S. Coast Guard and Air-Sea Rescue Sercices in particular. The procedures have been set down in the form of a series of specific doctrines, which include lines of responsibility and authority and communications, as well as operating tactics; Search and Rescue Manual, Reference 18.

Primarily, the many search and rescue doctrines have been established to handle the problem of locating aircraft, ships, and human beings lost at sea in an area which can be stated in some fashion (navigational fix, extrapolation of a known direction and speed of travel, for example). In the present problem, prediction of the capsule impact point within relatively narrow limits is expected, so that the area to be searched should be reasonably small. Secondly, it is desired that fairly short access times from impact to retrieve be obtained. Therefore, in certain respects, the established doctrines may not be usable without modification. Among other considerations would be the maneuvering limits of the search aircraft: if the actual area is very small, the aircraft may necessarily traverse a substantially larger area in performing the required search. Also, excessive maneuvering might result in disorientation and confusion of the observers. However, the established doctrines do provide a frame of reference with which to operate.

For aircraft, the most promising search patterns delineated in the Search and Rescue Manual are the parallel track patterns, used by one aircraft alone or by several aircraft working as a team. Use of other patterns such as expanding square would probably result in excessive maneuvering when applied to a small area.

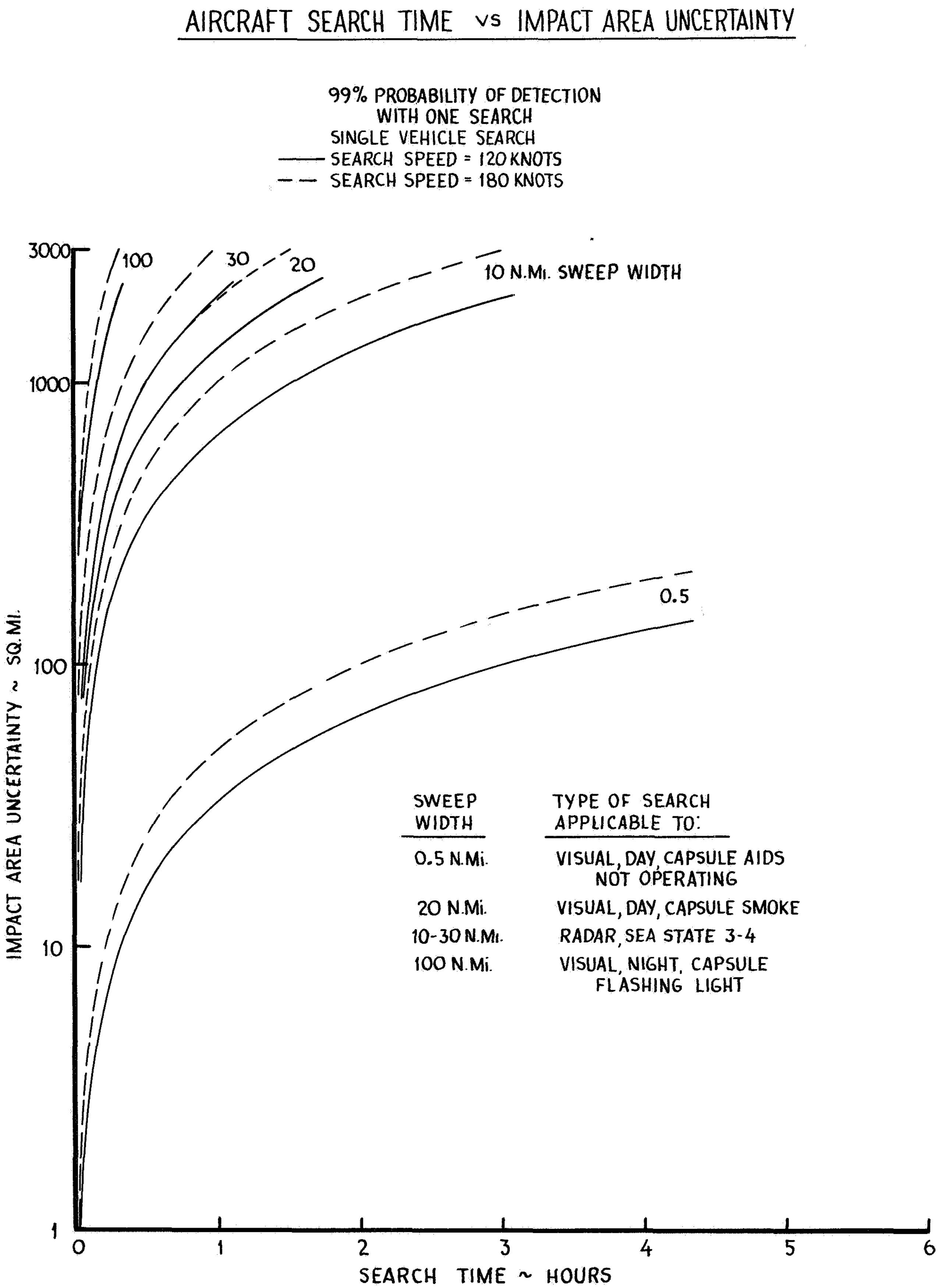

AIRCRAFT SEARCH TIME vs IMPACT AREA UNCERTAINTY
99% PROBABILITY OF DETECTION
WITH ONE SEARCH
SINGLE VEHICLE SEARCH
SEARCH SPEED = 120 KNOTS
SEARCH SPEED = 180 KNOTS
3000
1000
100
10
1
100
30
20
10 N.Mi. SWEEP WIDTH
0.5
IMPACT AREA UNCERTAINTY ~ SQ.MI.
0
1
2
3
4
5
6
SEARCH TIME ~ HOURS
SWEEP WIDTH
TYPE OF SEARCH APPLICABLE TO:
0.5 N.Mi.
VISUAL, DAY, CAPSULE AIDS NOT OPERATING
20 N.Mi.
VISUAL, DAY, CAPSULE SMOKE
10-30 N.Mi.
RADAR, SEA STATE 3-4
100 N.Mi.
VISUAL, NIGHT, CAPSULE FLASHING LIGHT

Fig. 16

Based on the search pattern data presented in the Search and Rescue Manual, the effect of search area size on time to locate the capsule has been estimated for a range of conditions of particular interest: day-time visual search both with no capsule visual aids operating and with capsule smoke operating, active radar search for the capsule in Sea State 3 to 4, and night-time visual search with the capsule flashing light operating. Figure 16 shows search time vs area for these conditions, assuming single vehicle search and a track spacing for 99% probability of detection in one search. The effect of search aircraft speed during search is shown for each condition illustrated; the effect of drift after impact, which would increase the area to be searched, and the corresponding time, has been estimated to be at most of the same order of magnitude as that shown for airspeed.

The variation in impact area size uncertainty to be expected is from almost 3,000 sq.n.mi. in area, about 30 n.mi. in radius, estimated by NASA for ground tracking during re-entry, down to about 40 sq. n.mi. for a local radar contact, assuming an APS-20 radar (carried by P2V, WV-2, and ZPG-2) located 120 n.mi. from the capsule. Figure 16 indicates that the 3,000 sq.n.mi. area would fall within reasonable capability of a single search aircraft using radar search or using visual means against operating location aids, requiring about two hours of search or less, but quite thoroughly beyond reasonable capability using visual search against the capsule alone. The 40 sq.n.mi. area would be within reason in any event, requiring only about one and one-quarter hours of search for the worst condition shown.

It is anticipated that should the capsule location aids fail to operate after impact, the capsule would be contacted first by radar, and dependence on visual search means would be left to the final moments of search. Following such a sequence, the area to be searched visually should be very small.

Thus, it appears that contact with the capsule may be reasonably expected to occur within about two hours or less after search of the impact area uncertainty is begun. The primary means of location would presumable be the capsule flashing light should impact and the beginning of search take place at night, and the use of active radar search techniques during the daytime. Daytime smoke emission from the capsule would provide a back-up means roughly equivalent to active radar, itself a secondary means at night.

If impact occurs at night and the capsule flashing light does not operate, there is no reasonable expectation of success using a visual search. This would also be the case were there to be a very heavy overcast, which would tend to obliterate the light at night or the smoke during the daytime. The usefulness of smoke would also deteriorate with wind. Therefore, to a great extent, the main reliance may fall on the use of radar. In order to supplement the radar detection capabilities, especially under overcast conditions, use of infra-red means might be attractive; a device for this purpose is understood to be under current test by the Air Rescue Service.

RETRIEVING REQUIREMENTS AND TECHNIQUES

This Part describes the various equipments and techniques that may be used to retrieve the Mercury capsule from the water. It is divided into four (4) parts as follows:

1 - General Considerations
2 - Types of Retrieving Gear and Operational Techniques of Recovery Vehicles
   a) Fixed Wing Aircraft
   b) Helicopters
   c) Airships
   d) Surface Vessels
   e) Submarines
3 - Weather and Environment - Effects of
4 - Summary

General Considerations

Recovery vehicles should have capability of retrieving the capsule from the sea and suitable provisions on deck for stowage or ability to transport capsule quickly to a suitable base. It is highly desirable that the occupant be examined and made available to the proper medical and interrogation personnel as soon as possible after retrieving.

It is desirable that the techniques for retrieving the capsule not require special training or skills. This means that special gear required to engage, hold, or accommodate the capsule should be simple and readily understood by competent seamen or airmen. The Mercury Program will involve a large number of military and Naval vehicles and personnel. Many of these will necessarily be on a standby or relief basis. Postponements and delays in the orbital shots are inevitable. Replacements for the units "on station" will undoubtedly be required. In certain cases units may be rotated with others which are serving a duty of national defense. All of these units must be equally capable of carrying out their assignment in the Mercury program and this can only be done if the requirements are simple and easy to understand.

It is important that instructions on how to enter the capsule, while it is floating in the water, and remove the occupant, who may be unconscious, should be widely disseminated to all agencies, military and civilan, who might be involved in the recovery activities. If it is impossible to do this safely in the water it is equally important that this also be made generally known. A special harness or provision on the pilot's clothing to attach a rope should be provided so that he could be hoisted or pulled out of the capsule. Removal of the man from the capsule while in the water should be considered in emergency only and attempted only if the capsule retrieving gear is inoperative or, as in the case of the available seaplanes, this retrieving gear is not available. Even then the decision of separate removal must be based on (1) weather and sea state; (2) proximity of vehicles carrying capsule recovery gear; (3) condition of capsule, i.e. damaged, sinking, etc. A fourth consideration might be the condition of the man inside. If, by radio or visible signals, it is learned that he is in need of immediate medical attention or that the interior of the capsule has become uninhabitable then the speed with which he can be evacuated would be the dominating factor.

Evacuation of the man on the water is dangerous except in the smoothest sea. Shipping of water in the top hatch is inevitable in rough seas even with the floatation bags and with the occupant in normal physical vigor. If, however, he cannot assist himself, the side opening must be used and the rescue is likely to become a race of effecting his removal before the capsule has shipped enough water to cause it to sink. It is recommended that such evacuation be done from a life boat or a life raft of not less than 10 men capacity. A life boat or 10 man raft offers sufficient size and buoyancy that the top of the capsule can be pulled over into it and lashed in place while the rescue is being accomplished. This arrangement would prevent the shipping of harmful amounts of water while the side hatch is open. A 10 man life raft weights 114 pounds and all large seaplanes and amphibians are equipped with this size or larger. Helicopters too small to lift the capsule can also carry this raft and drop it and a rescue crew near the capsule. After the rescue is effected, they can all be hoisted up into the helicopter.

The Air Rescue Service of the USAF has two-man, para-rescue teams trained for all emergencies except surgery. These men could drop an MA-1 kit, consisting of two 20-man life rafts one at each end of an 880-foot line with survival bundles located each 200 feet along the line. The rafts, having a greater freeboard than the bundles (or the capsule), would cause the line to form a horseshoe shape. If properly dropped it would encircle the capsule. The para-rescue team could assist the capsule pilot and render first aid, if necessary.

Types of Retrieving Gear and Operational Techniques of Recovery Vehicles

a) Fixed Wing Aircraft

There are no fixed wing amphibians or seaplanes in service large enough to load the capsule from the water. Therefore, the only role these aircraft can take, aside from aiding in the search, is to rescue the man separately from the capsule.

The techniques for effecting such rescue are time honored and simple. The aircraft is taxied nearby and, if there is a wind, held in position with engine power. A life raft secured to the aircraft with a long painter is put overboard and one or two men row to the capsule. As an aid to rescue, some aircraft carry a portable platform which can be attached on the outside below the main entrance door at approximately the water level. One or two men secured to this platform with safety belts and provided with boat hooks and snatch lines can retrieve life rafts or floating personnel under very adverse sea states. In calm weather it would be possible to contact the capsule from this platform and make a direct rescue of the man inside.

There are two large Navy seaplane types that do have the capability of retrieving the capsule. Unfortunately, they are not now in service. The ten Convair R3Ys (Tradewinds) in mothballs at Alameda have a side door aft of the wing which is large enough to admit the capsule. An overhead hoist can be swung out of this opening for lifting the capsule from the water. The four Martin JRM (Mars) flying boats, which are being modified for another use, have an ideal retrieving system. A monorail extends outboard along the under surface of the wing (hoist

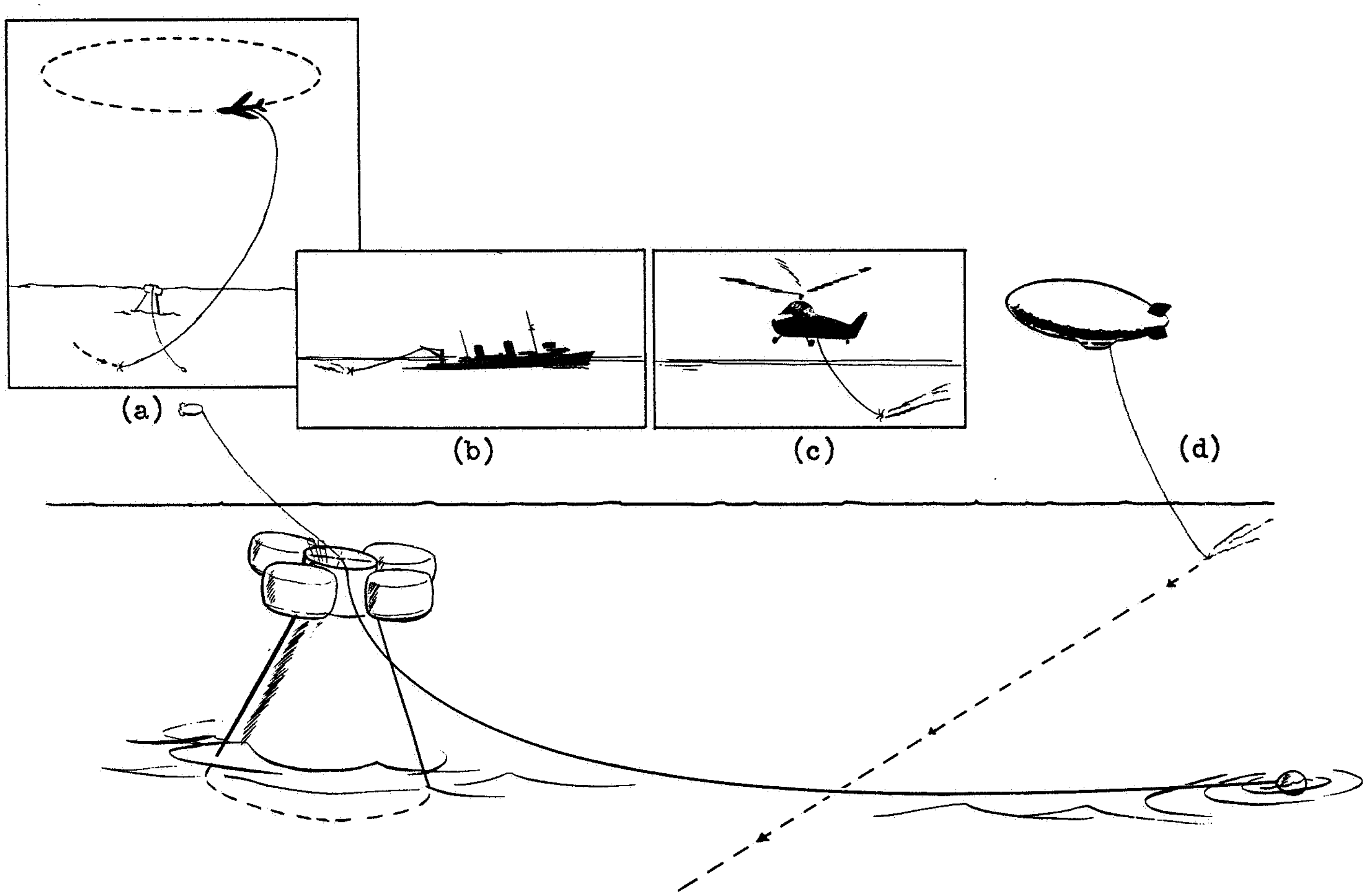


FIG. 17

CAPSULE PICK-UP - FLOATING RETRIEVING LINE

(a) Long Line Technique - Orbiting Aircraft
(b) Ship
(c) Helicopter
(d) Airship

capacity = 5,000 lbs.) The capsule could be picked up at a safe distance from the hull and pulled along this rail directly into the hull through a 92" x 99" opening existing under the wing for this purpose. Neither seaplane was designed for rough seas operation, but the R3Y has somewhat greater capability than the JRM in this respect. The JRM is generally thought to have a sea state 3 limit.

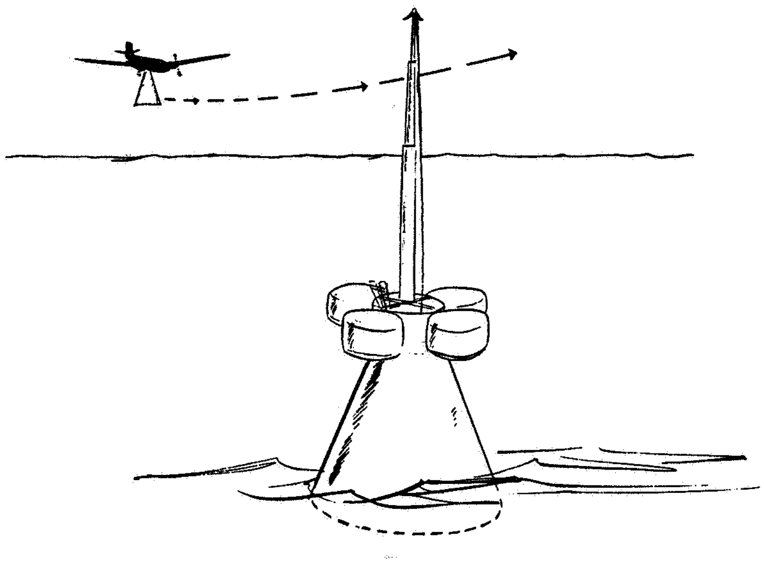
Fixed wing aircraft using "snatch" techniques either in the air during the descent of the capsule or after it reaches the water may bring an important contribution to the recovery effort (Figures 18 and 24). These systems are in use now on C-119 aircraft and have been used for air-to-air pick-up of objects weighing up to 1000 pounds and for water pick-ups of weights up to 800 pounds. The techniques for recovering the capsule would be similar to these pick-ups but the retrieving gear would have to be stronger and larger aircraft might be required. (see Figure 18) It is doubtful that development of either one of the above recovery systems for effective operational use could be accomplished prior to the first orbital shots. However, the potential savings in recovery time and overall cost for water-to-air snatch technique would seem to justify immediate further development. This system is considered in the category of future improvements to recovery and is discussed in a later section of this report.

Another type of aerial recovery from fixed wing aircraft which might be applicable to the Mercury Program is the "long line" technique - Figure 17 . This consists of a long line - over 1000 feet - attached to an airplane with a hook or grappling device at the lower end. When the aircraft circles in a small orbit, the device on the lower end of the line is impelled to the center of the orbit where it remains relatively motionless except for the rotation imparted by the circling aircraft. Very accurate placement of the device can be attained in this manner but so far it has been used only for light weights and it is not at present applicable for capsule recovery. This system is also discussed later.

In addition to the advantages mentioned above for the snatch-off-the-water technique, this "long line" system might be adaptable to many more types of aircraft if the line need not be reeled in and the capsule landed by the same technique. Also, this method is one of the very few, if not the only one, that might be used successfully in remote inacessible areas on land. The advantages that either the "snatch" or "long line" techniques would appear to offer in terms of reduced access time and number of vehicles, as discussed elsewhere in this report, indicate the advisability of a maximum development effort to make them available as soon as possible.

b) Helicopters

Helicopters, in the largest sizes, are well suited to retrieve the capsule under any but the most adverse weather conditions. Helicopters used by the Navy, Marines, Air Force and Coast Guard have played a large role in the recovery of objects and persons from the water, and recovery of the capsule does not present a problem except that its weight eliminates the use of the smaller types.



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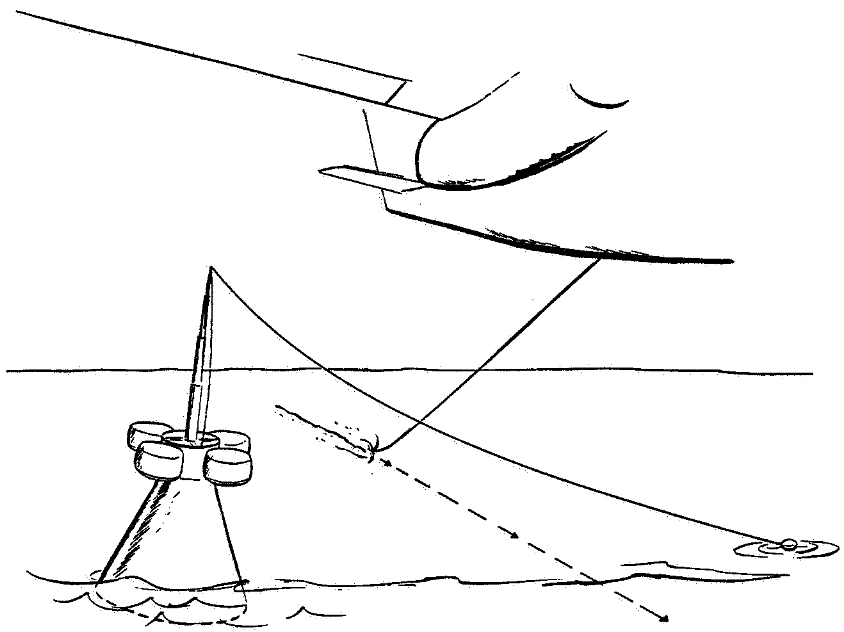


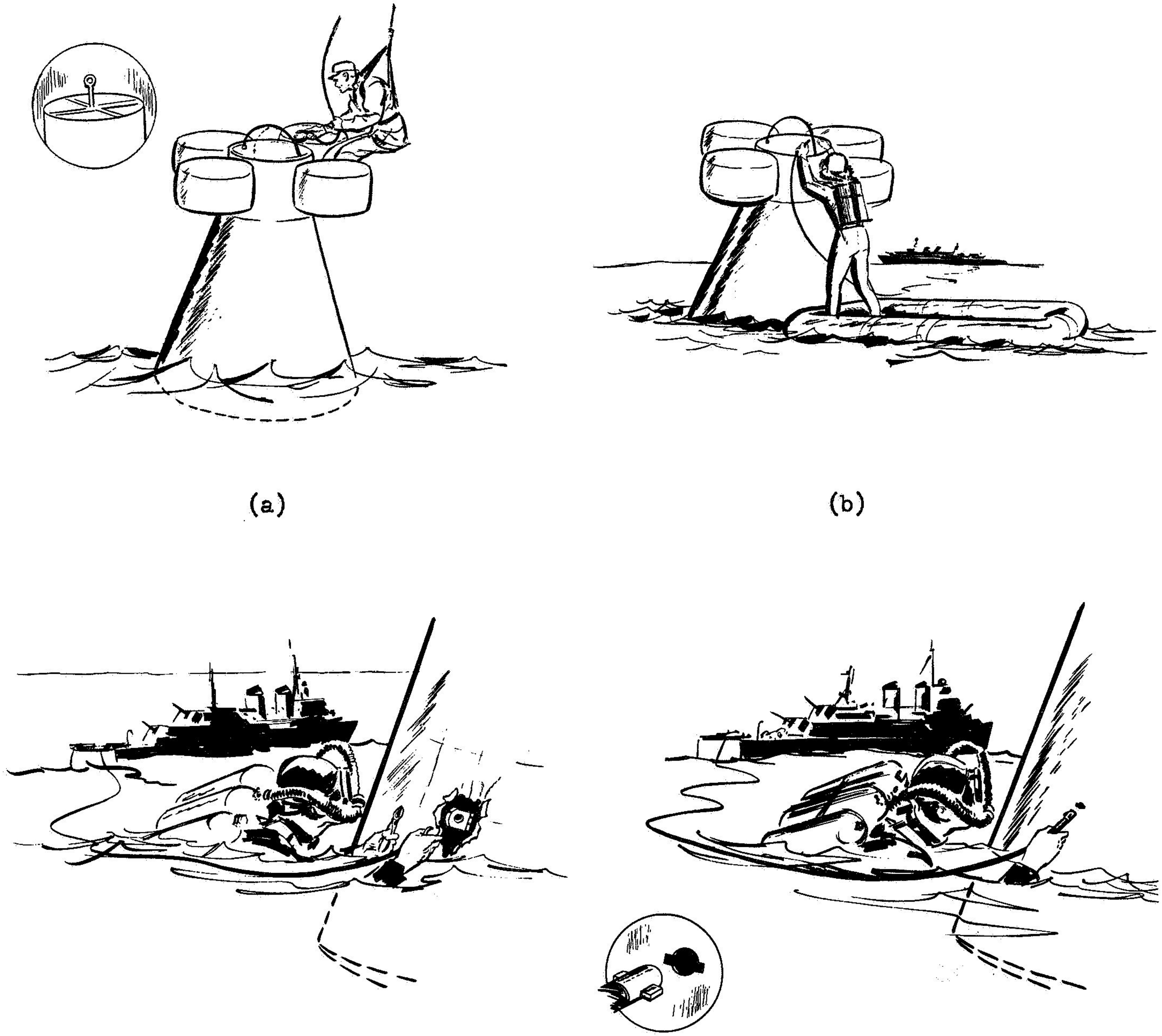
(b)

FIG. 18

CAPSULE PICK-UP - WATER-TO-AIR SNATCH

(a) All American System - Suspended Line on Aircraft Engages Elevated Hook on Capsule.

(b) All American System - Suspended Hook on Aircraft Engages Elevated Retrieving line on Capsule.



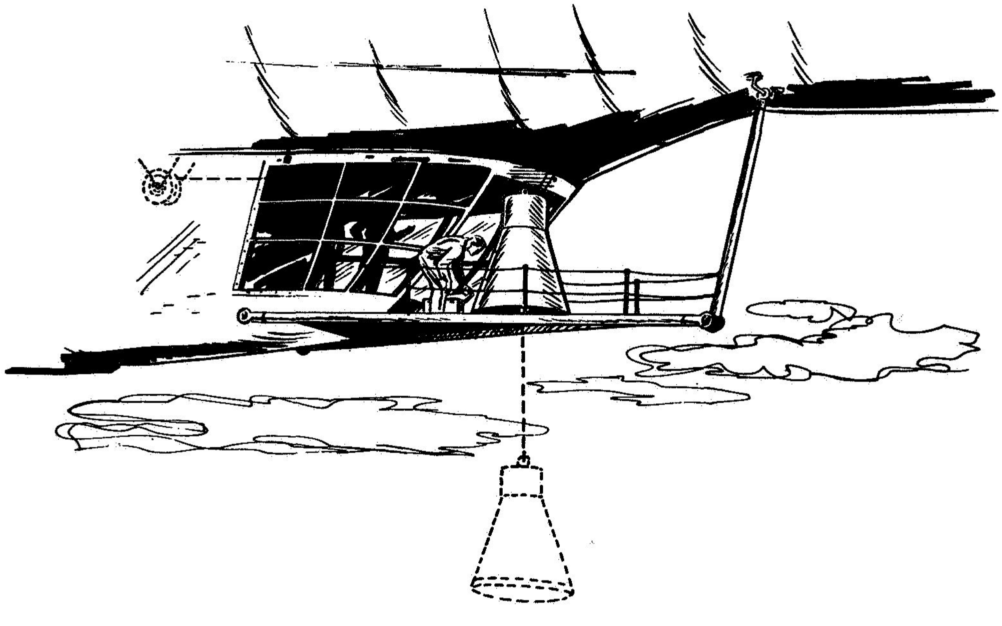
(a) (b)

(c) (d)

FIG. 19

CAPSULE PICK-UP - MANUAL ATTACHMENT SYSTEMS

(a) Attachment to Helicopter or Airship Hoist. Bail or Lifting Eye on Capsule.
(b) Attachment to Ship Boom or Davit. Bail or Eye on Capsule.
(c) Attachment to Ship Boom or Davit. Hinged Eye on Capsule.
(d) Attachment to Ship Boom or Davit. Special Connection on side of Capsule.



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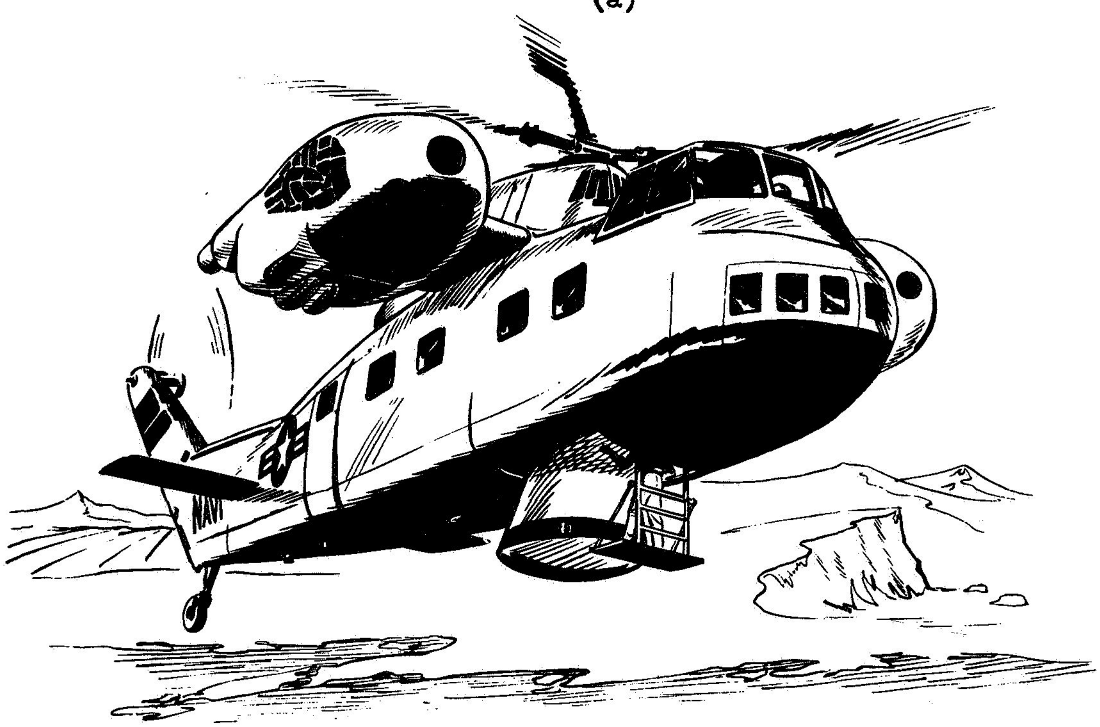


(b)

FIG. 20

CAPSULE PICK-UP - HELICOPTER AND AIRSHIP ACCOMMODATIONS

(a) Sikorsky Arrangement - HR2S-1 Helicopter
(b) Naval Air Station, Lakehurst, Arrangement - ZPG-2 Airship.

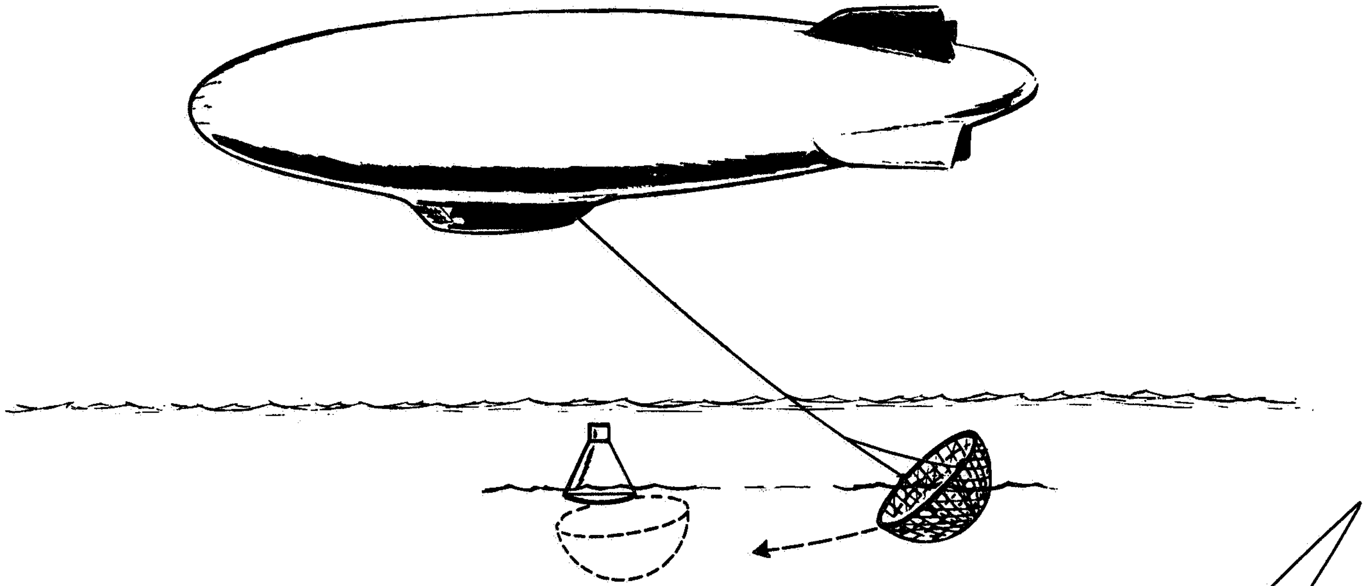
Navy, Marine, Coast Guard and Air Force helicopter pilots and crews are accustomed and trained to operate over water and ship bases. The Army, also, has a large number of helicopters available, but their personnel may require certain specific over-water training. According to Army authorities this should be no problem.

Three types of helicopters stand out in having the capability of retrieving the capsule without costly modification and they exist in sufficient quantity to satisfy reasonable logistics requirements. One is the Sikorsky HR2S-1 (Marines), H-37A(Army), another is the Sikorsky HSS-1(Navy), H-34(Army), HUS-1(Marines), and the third is the Vertol H-21B(USAF), H-21C(Army).

The perferred method of attachment to the capsule is by means of a hook connected to a bail or eye on the capsule. A crewman would effect this attachment from a sling while the helicopter hovered overhead. Reference Figure 19. The HR2S-1 (H-37A) is equipped with a hoist which according to Sikorsky Aircraft Company, can be easily adapted to lift the capsule partially through a hatch in the floor. A platform can be provided to obtain access to the interior of the capsule while in this position and the occupant may be removed. (Reference Figure 20). The capsule flotation bags will be destroyed when the capsule enters the hatch unless they can be deflated or jettisoned prior to hoisting. At a normal radius of action of 165 nautical miles, 1500 pounds of useful load including medical personnel and supplies can also be carried.

The Sikorsky HSS-1 (H-34) (HUS-1) and the Vertol H-21B (H-21C) do not have a hoist winch of sufficient capacity to lift the capsule but they are equipped with a 5000 pound, four point suspension cargo sling. This four point suspension can be connected to a single hook for attachment in a manner similar to the Sikorsky HR2S-1. In this arrangement, the capsule would be carried slung below the helicopter to a suitable landing spot. In a calm sea, recovery of the occupant of the capsule could be effected prior to pick-up by means of a hydraulic personnel rescue hoist. A helicopter crew man would ride the sling down to the capsule and assist the occupant. Reference Figure 19. Due to the flotation bags at the top of the capsule, the down-wash from the rotor blades at normal hovering heights may have an adverse disturbing effect. Greater hovering heights may be required. It is highly desirable that the occupant wear a harness or provision for attaching a hook. Special attention should be paid to the interior arrangment of the capsule so that rescue of an unconscious occupant can be easily made under these conditions. At a radius of action of 120 nautical miles, approximately 500 pounds of useful load can be carried in these helicopters in addition to the capsule. This inclues two crewmen, life raft, etc.

Helicopter pick-up can also be made by dragging a grappling hook through the water on the end of a cable until it engages a retrieving line attached to the capsule as shown in Figure 17. This procedure would be used if (1) no shackle is provided for attaching a hook, (2) the seas were too rough to lower a crewman for manual connection, (3) threatening weather makes it advisable to remove the capsule as quickly as possible, (4) the capsule is in a sinking condition and must be gotten out of the water as quickly as possible. With this type of



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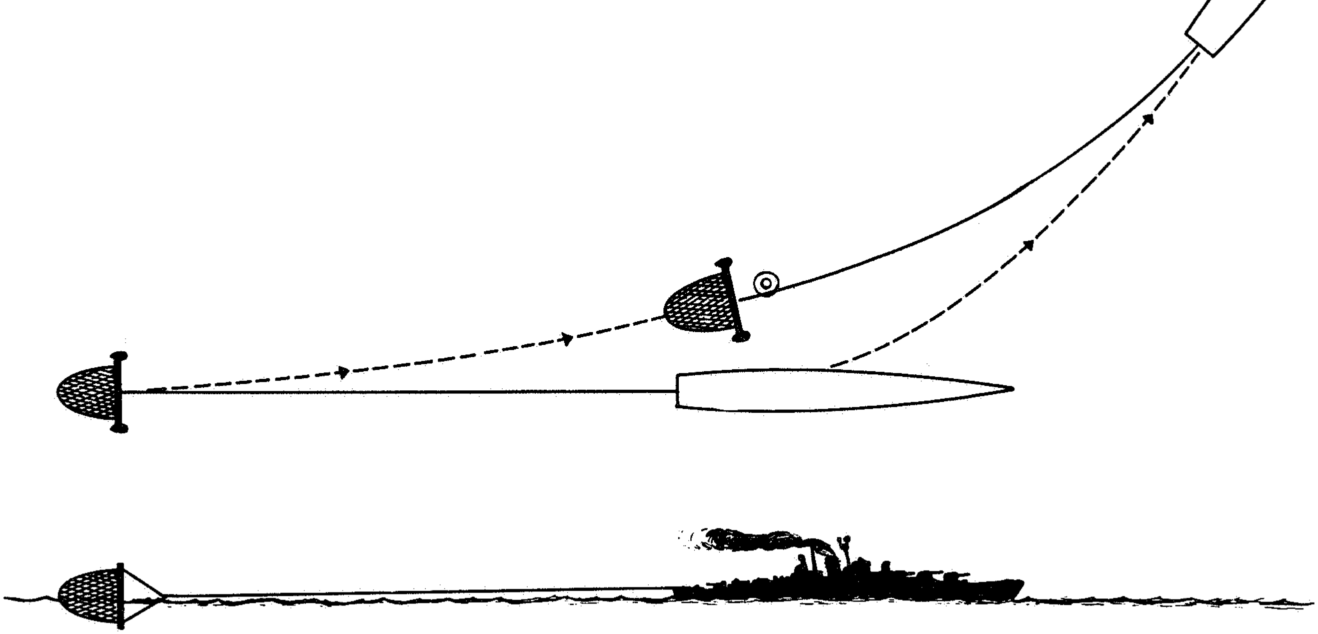


(b)

FIG. 21

CAPSULE PICK-UP - HEMISPHERICAL DRAG NET

(a) Airship or Helicopter
(b) Ship

pick-up special provisions would be required for the HR2S-1 crew to hoist the capsule up to the cabin because of the interference from the retrieving line float and end connections, or it would have to be carried slung below the helicopter to a suitable landing spot.

If no provision is made on the capsule for attachment of a hook or the installation of a retrieving line or other grappling device, the use of a net devised so that it can encompass the capsule from underneath would be required. Two ideas for this type of net are shown on Figure 21 and 22. They are too large to house within the helicopter but can be carried below it in a reefed condition ready for immediate release. It would not be possible to hoist this net into the cabin of an HR2S-1 helicopter and the capsule would have to be carried slung below to a suitable landing spot. The drag of this net in the water will require higher power in the hovering position and a higher than usual hovering altitude may be necessary to avoid disturbing the capsule from the rotor downwash while the net is being maneuvered under it.

A method used by the Marines in tests of retrieving a dummy capsule is to drag a flat net suspended by a helicopter or ship's boom across the capsule to engage hooks on the sides near the top. See Figure 24. This system would be very effective provided the capsule was configured without the flotation bags and the hooks were installed.

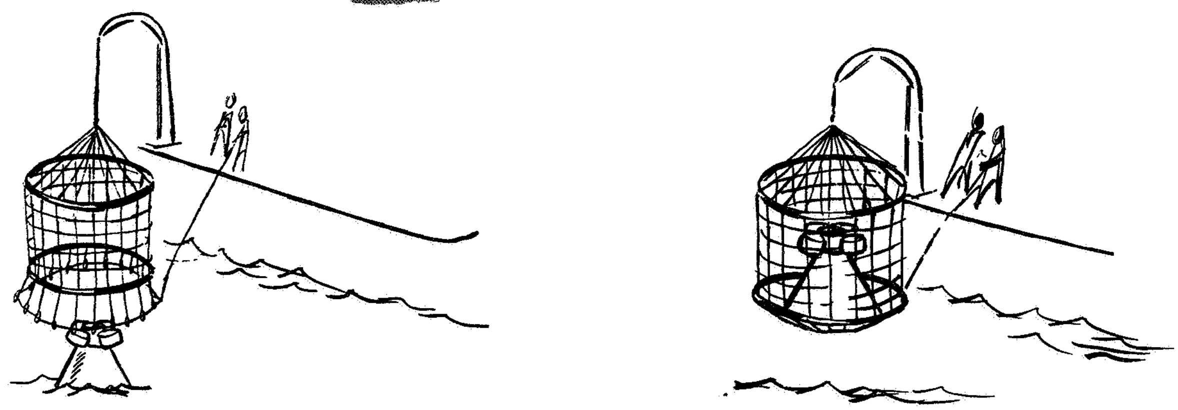
c) <u>Airships</u>

Airships presently in use by the United States Navy have characteristics of endurance, hovering ability, cabin space, winch capacity, detection capability and staging versatility which justify them for a role in the capsule recovery operation.

The Model ZPG-2 airship is the most available type. It has a normal radius of action of 1100 nautical miles (plus reserve) at a speed of 40 knots. Hoist winch capacity is 4000 pounds. With 1800 pound load, reel-in rate is 160 feet per minute.

The size of the winch opening is too small to permit entry of the whole capsule into the car, however, NAS personnel at Lakehurst, New Jersey, have proposed fabricating a special external platform at the rear of the car as shown in Figure 20. The capsule would be pulled up through the open bottom after which the platform flooring would be set in place and the capsule lowered on it. This arrangement would permit easy and comfortable removal of the man.

Techniques of retrieving are similar to those described for helicopters. The drag line method for engaging the capsule retrieving line can also be used as it is now used to pick-up 1000 pound floating fuel bags. An advantage the airship has over the helicopter is the absence of downwash from the rotor blades.



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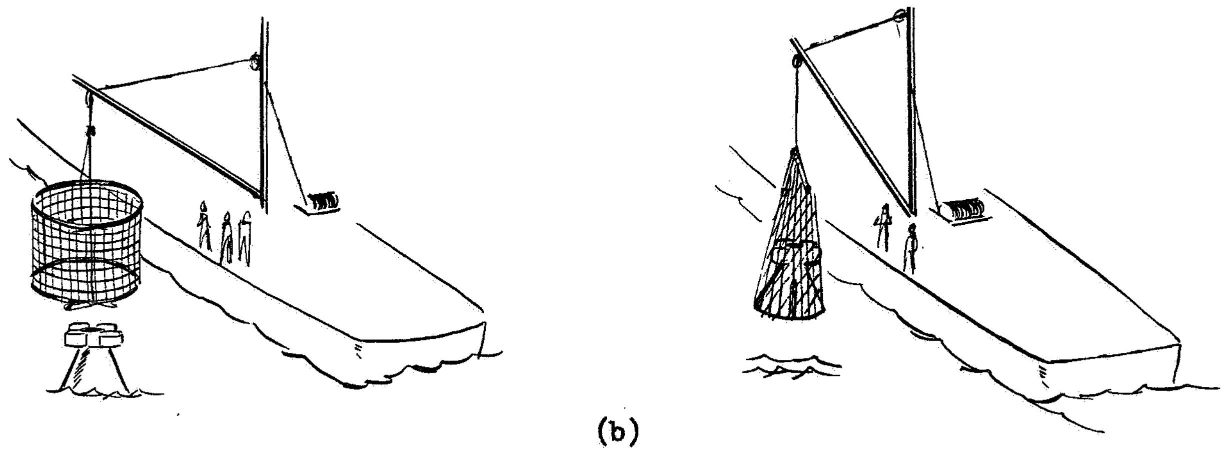


(b)

(c)

FIG. 22

CAPSULE PICK-UP - CAGE TYPE NET

(a) Pucker Line
(b) Clam Shell - Ship Mounted
(c) Clam Shell - Carried on Helicopter or Airship

After the capsule is hooked, water ballast is released from the airship to compensate for the weight and the lifting is steady and easy. Due to their greater size, high cost and lower speed, airships have not been used for air-sea rescue missions as extensively as helicopters and a program of tests in dummy capsule recovery might be necessary before they could be given an assignment in the Mercury operations. They have long endurance - normally 55 hours - and ideal search capabilities - both electronic and visual. There are substantial savings to be realized when the detection vehicle can also be used for retrieving and tests of this system should be expedited.

d) Surface Vessels

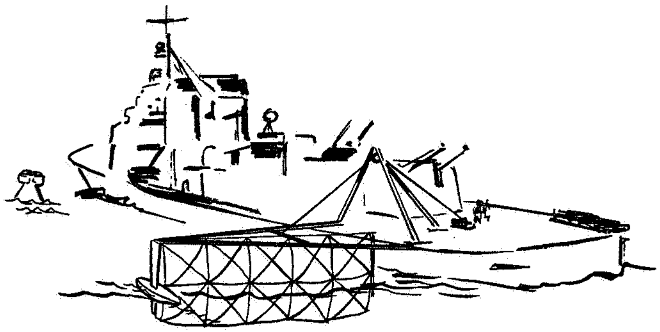
Surface vessels have the advantage over other recovery vehicles of being able to stay "on station" much longer and under much worse weather and sea conditions than aircraft. They offer a stable and, in most cases, roomy platform for retrieving gear and the weight of this gear is not as important as it would be on aircraft.

Most ships have hoist or winch capacity large enough to lift the capsule out of the water and deposit it on deck; however, in all but a few cases, this hoisting means is a life boat davit. Davits are relatively short and Navy experience with dummy full scale capsules has shown that they may bump the side of the ship while being hoisted. In a rolling or rough sea the side of the ship must be thickly padded to prevent damage to the capsule.

Buoy tenders are considered to be the best surface vessels for retrieving of the capsule. They are equipped with long booms so that there is no danger of the capsule striking the side while being hoisted and their crews are well trained in retrieving buoys weighing up to several times that of the capsule. However, buoy tenders are not plentiful and it is doubtful if an effective number could be employed in some of the more remote areas to be covered in the Mercury program. Their relatively low speed while traveling to the capsule is a handicap when minimum recovery time is a requirement.

All vessels are provided with hooks of various sizes, and if the capsule is equipped with a bail or shackle for hoisting, the recovering operation would not be difficult in moderate sea states. The standard procedure would be to heave-to a short distance from the capsule and let the hook be attached by frogmen or a crew in a small boat - reference sketches, Figure 19. After that the capsule would be drawn to the vessel and hoisted aboard.

If no hoisting bail or shackle is provided on the capsule, a cage of the type shown on Figures 21 through 23 could be used for the retrieve. In this instance, the capsule would be "lassoed" by the boat crew and then pulled in close enough to the vessel so that the cage could be dropped over it from a davit or boom.



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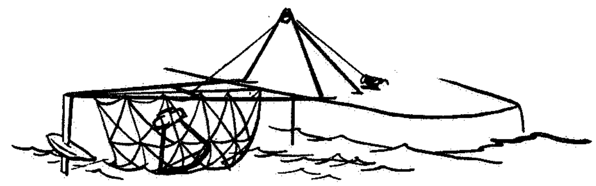

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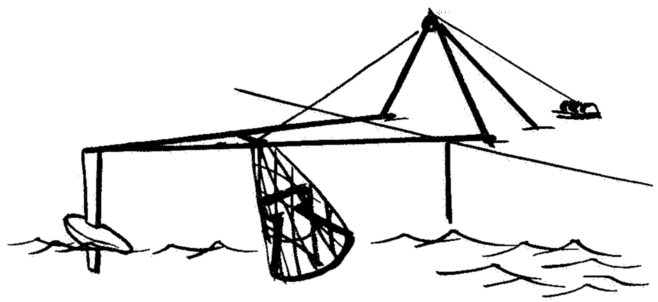

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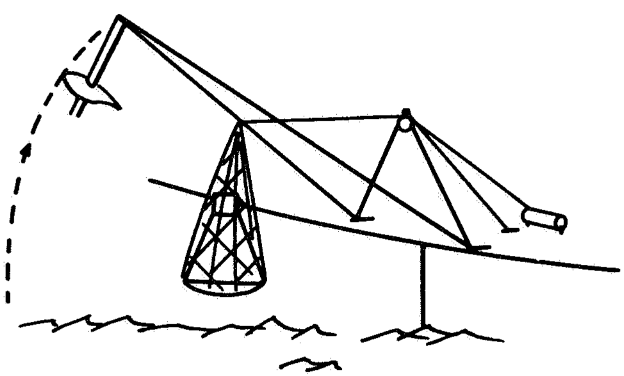

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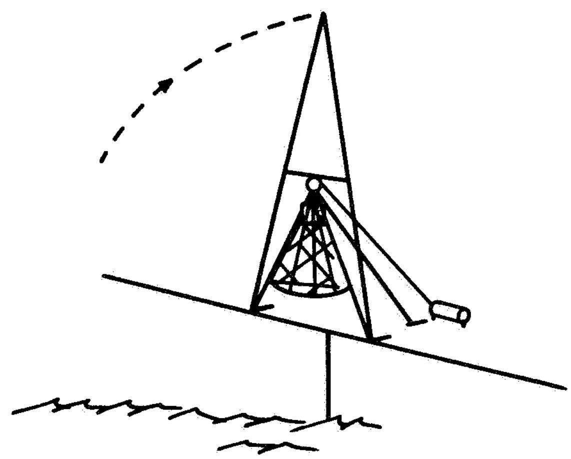

(e)

FIG. 23

CAPSULE PICK-UP - SHIP MOUNTED SIDE NET

(a) Net in Position.
(b) Intercepting the Capsule.
(c) Net Drawn around Capsule
(d) Hoisting Capsule from Water
(e) Capsule deposited on Deck.

In the event of rough seas, the commander of the rescuing ressel would probably heave-to upwind from the capsule in order to provide smoother water for his crew to effect the attachment and retrieve. Oil might be released to further reduce the roughness. However, in this operation, the ship, due to its larger wind area, will drift down on the capsule and extreme care and skill must be used to avoid a damaging contact.

To save time and to eliminate the necessity for the ship to heave-to close to the capsule, a device that permits retrieving while the ship is underway is desirable. An idea for such a device is shown on Figure 21. This consists of a special net towed behind the ship on a course to intercept the capsule. After "netting", the capsule is drawn to the ship and attached to a boom hoist or boat davit. This device does not require alteration to existing ship structure.

Another arrangement that permits retrieve of the capsule while the ship is underway is shown on Figure 23 . This consists of a large net mounted on an "A" frame extending approximately 50 feet from the side of the ship and supported on its outer end by a floating pontoon. As soon as the capsule is "netted", the entire frame is rotated upward and inward and the capsule is deposited on the deck. This arrangment is easy to handle and control and should prove efficient in all kinds of weather. However, it is a structural device that must be fitted and installed on each ship and will require alterations or revisions to these ships. It would be admirable where the expected capsule impact area could be covered by only a small number of ships or the ships were the fast hydrofoil type. Reference section on future developments.

If the capsule is provided with a floating retrieving line, as shown in Figure 17, an underway pick-up can be made by dragging a grappling hook through the water on the end of a cable so that it engages the line. This cable could be suspended from a boom or outrigger. Due to the length of the retrieving line and possible interference of the small float on the end of the line with hoist pullies, it would be necessary to use a snatch block or open block on the line below the float in order to permit hoisting the capsule to the deck. When the size of the float is known, the subsitition of rollers for the pulleys would simplify the hoisting procedure.

e) Submarines

Submarines have long played an important role in rescuing flyers down at sea and they have characteristics of "on station" endurance, personnel accommodations and detection capability that also fit them for a part in the capsule recovery program.

Retrieving operations are unique yet comparatively simple. The submarine would heave-to nearby and send a program or crew in a life raft to "lasso" or attach a line to the capsule. The capsule would then be brought alongside the submarine which would then submerge sufficiently to permit the capsule to be floated onto the deck (the capsule draws less then 2 feet) and be lashed in place. The submarine would then rise and the capsule would be high and dry on a secure deck and ready for easy egress of the occupant.

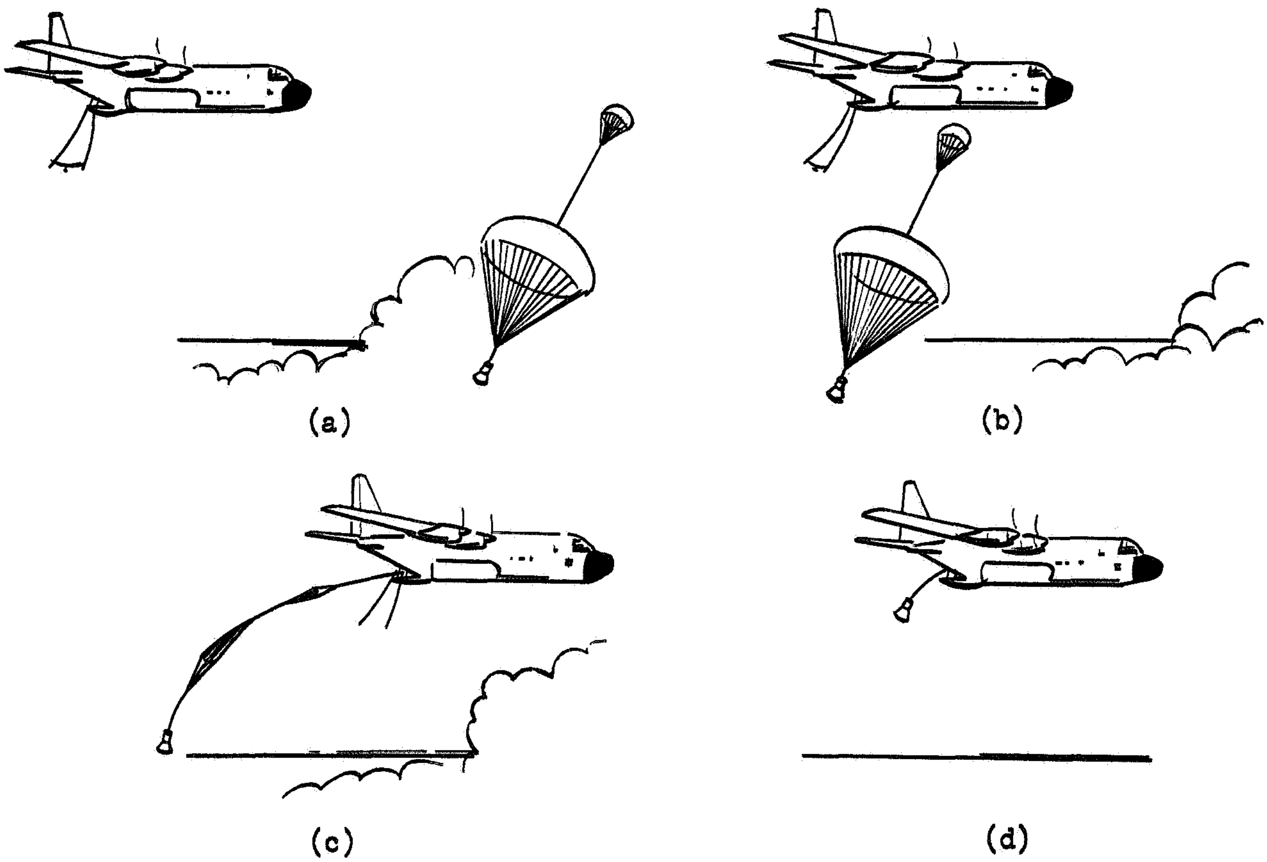

FIG. 24

CAPSULE PICK-UP - AIR-TO-AIR SNATCH

(a) Approach
(b) Pick-Up Pass
(c) Contact
(d) Retrieve

The submarine would not be able to submerge with the capsule on deck because of possible damage or loss and would have to proceed on the surface to the nearest ship or base where it could be taken off. In an emergency, the capsule would be removed from the submarine deck by means of the water retrieving methods on vehicles previously discussed, i.e., helicopters, airships, air snatch, long line pick-up, etc.

Advantages of submarine retrieve are that it is comparatively simple in normal conditions and no special retrieving gear is required on either the capsule or submarine. Ordinary lines can be used from the submarine and if no handling provisions are incorporated on the capsule these lines can be lashed around it and securely tied to the deck.

Weather and Environment - Effects of

This Part will describe the applicability of the foregoing recovery systems in relation to weather and sea conditions and will point out the limiting factors that may govern in each case.

a) Time of Day

Daylight is best by far for all pick-up operations. However, it is realized that other factors such as search and detection may outweigh the advantages of daylight for the actual retrieving operations. Radar detection is equally efficient in day or night but a flashing light on the capsule can be noticed at a much greater distance at night than the capsule can be seen by day. The best hours for daylight detection are between 10:00 A.M. and 2:00 P.M.

Water landings with fixed wing aircraft at night in the open sea regardless of wind or wave conditions are hazardous and should not be attempted except in emergency. Air-to-air snatch requires high visual acuity and judgment and must be restricted only to daylight in clear weather. Water-to-air snatch using the elevated hook on the capsule as described previously is feasible provided the capsule has a flashing light and the aircraft is equipped with a radio altimeter coordinated with an automatic pilot. It would be desirable to have a powerful searchlight type AN/AVQ-2 or equivalent as used on anti-submarine aircraft mounted on the recovery aircraft. Water-to-air pick-up using the "long line" techniques must, at the present time, be limited to clear daylight. However, it is possible that electronic aids can be developed which will make this technique less dependent upon visibility conditions.

Most helicopters are equipped with or have provision for the installation of downward facing lights which are suitable for normal rescue work at hovering altitudes. Retrieving times for the capsule using either the hook and shackle, retrieving line or cage net would be roughly doubled for night as compared to day. When using a grappling hook, it might be necessary to make several passes at the capsule to determine the orientation of the retrieving line in relation to the capsule.

The same general considerations apply to airships as for helicopters in night operations.

Ships will have the fewest problems of all vehicles for effecting night time retrieving as compared with day time. They are usually equipped with multiple searchlights spaced apart so that the effects of shadows are minimized.

b) Wind and Waves

Wind and waves are considered together because the latter is dependent on the former except for the effects of tides or earthquakes. Although waves are mostly caused by winds it is often possible to have a large wave system with little or no wind or the wind direction could be in a different direction from the waves. Waves generated by storms can travel great distances because the loss of energy due to the viscosity of the water is low but as they leave the generating area they become smoother and are known as swells.

Long swells with heights of up to 9 or 10 feet and wind velocities of up to 12 knots do not degrade normal recovery capabilities appreciably. But wind velocities of 16 to 21 knots can generate waves of between 6 to 9 feet in height which will be much steeper than swells and will contain many white caps and a chance of of spray which might at times obscure the capsule. Seaplane landings would be hazardous. And the possibility of removing the occupant from the capsule in the water by means of a life raft or small boat would be dangerous to both the occupant and the rescuers.

Retrieving by helicopter or airship would best be done by grappling the capsule retrieving line with a cable. This permits a minimum of time at low altitudes under possible gusty conditions. Retrieving by use of the submerged net as shown in Figure 22 would be more difficult for helicopters or airships in winds of more than 16 knots. The abrupt vertical accelerations due to the waves added to the waterdrag and the wind drift would require skillful control of the vehicle to insure accurate placement of the net under the capsule.

Surface vessels have the highest capability of all vehicles in retrieving the capsule in winds up to 21 knots or greater. A subsequent Section of this Report on Weather and Environment notes that the probability of encountering winds of this velocity or greater during the months of July and August are about 15% of the time in the Canary Islands abort area and only 2% to 4% in the other expected impact areas. Therefore, surface ships having bad seas retrieving gear, i.e., nets and grappling means for retrieving while underway, should be considered for the Canary Island area.

c) Other Weather Considerations

The Mercury capsule impact areas are in temperate or tropical zones, and therefore, cold weather problems will not be encountered. Aside from wind conditions, which have been discussed above, the worst effects of weather will be fog and rain. High temperatures and humidity will influence the range and performance of aircraft - particularly helicopters - but allowance for these factors is made in the applicable Sections of this study.

The greatest problem posed by fog and rain is, of course, visibility - for search and detection - and electronic aids, some of which are also affected by the moisture content of the air, must be relied on almost exclusively. Aircraft, helicopters and airships must be carefully controlled from a central authority in the local search area in order to prevent collision with each other if more than one is involved. Surface ships have the best capability for retrieve in these conditions. Almost all of the methods described previously could be used. Since the actual retrieving operations are conducted at very close hand only the very densest fog might slow the work. Usually at such times the wind and sea are calm and the retrieving would be helped if the capsule were equipped with fog horn or bell.

Summary of Retrieving Vehicle Capability

This summary is based solely on the retrieving capability of the various vehicles. Transit speed, availability, search and detection capabilities of the vehicles are not considered in the evaluations. It should be remembered too, that a second-choice system when handled by a highly competent crew may do a better job than can be done with the best system under the control of a less-skillful operator.

a) The best retrieving vehicle is a ship of a size large enough to load and accommodate the capsule. Examples of such ships are destroyers, cruisers, small carriers, buoy tenders, etc.

These ships can carry and use any or a combination of all retrieving gear that can be carried on the other vehicles. In addition, they can carry gear that cannot be carried on anything else, i.e., large side mounted nets as shown in Figure 23, thus making them more adaptable for all-weather conditions. In short, a surface vessel can retrieve under normal weather conditions as well as any other vehicle and can retrieve under bad weather conditions better than any other type of vehicle.

b) Submarines are considered almost equivalent to ships in retrieving capability. The relatively simple way in which this can be accomplished under ordinary conditions is an advantage. However, due to their lower freeboard, submarines, in bad sea states, would not be as capable as ships.

c) Next in order of capability is the HR2S-1 helicopter. This machine can be easily modified so that the capsule can be drawn part way into the cabin and permit release of the occupant in flight and it is large enough to contain emergency medical equipment and personnel. If there is no provision on the capsule for the attachment of a hoisting hook this vehicle could carry a basket type net as shown in Figure 21.

d) The smaller helicopters, Sikorsky HSS-1 (H-34) (HUS-1) and Vertol H-21B (H-21C) follow the HR2S-1 in retrieving capability. They are not able to house the capsule and the occupant cannot be removed except in good weather conditions prior to the pick-up.

e) Airships seem to be equal to helicopters in retrieving capability and have better facilities for caring for the astronaut, but they have been placed below helicopters until pertinent tests have been made to substantiate their capabilities for this operation. They are less maneuverable than helicopters.

f) Large seaplanes, such as the Martin JRM (Mars), which has an ideal installation for retrieving the capsule, are placed lower on the list than might otherwise be deserved because of their limited sea state capability. If sea state 3 or less were assured, the Mars would closely follow ships in retrieve capability.

g) Fixed wing aircraft using "snatch" or "long line" techniques place last in capability for the following reasons:

1) The capsule must be equipped with provisions to elevate a hook and/or eject a retrieving line after entering the water. Such provisions are not at present in effect.

2) Much design and test work is required to demonstrate capability of picking-up the capsule with these techniques.

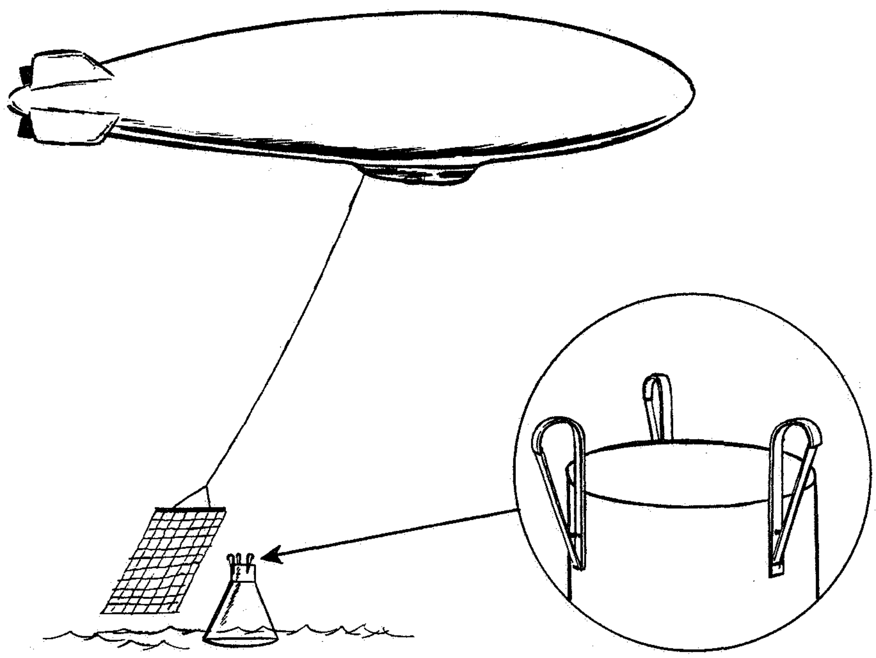

FIG. 25

CAPSULE PICK-UP - FLAT TYPE DRAG NET

Operable from Airship or Helicopter

COORDINATION

For the rapid recovery of the first manned satellite from wherever it lands on the surface of the earth, it is imperative that arrangements be made in advance for close coordination of world-wide forces. Smooth coordination will depend, of course, on the proper planning for division of responsibility, staging, logistics, tracking, computing and communications. Of first importance is the requirement that there be a plan of action for every conceivable landing place. In this study primary emphasis is placed on coordination among the U.S. Government forces involved in covering the "high probability" areas, all of which are in tropical and temperate parts of the North Atlantic Ocean. Arrangements should be made in advance, however, with as many countries as possible over which the satellite might pass, to use their forces and facilities and/or to allow us to use ours for the search and recovery of the capsule, should it appear to land in a low probability area under their control. Similar arrangements are currently in effect between the U.S. and some neighboring countries for search and rescue operations. (Appendix E of Reference 18), and might be extended through the cooperation of such existing international organizations as the ICAO, NATO, SEATO, etc.

Major roles will be played by the computing and communication center in the Washington, D.C. area and main control center at Cape Canaveral. Direct lines will connect these two, as well as other important points more fully described in the following section on Communications. The computing and communication center will serve as the main communications terminal. It will contain appropriate switching and monitoring facilities and will be in continuous contact with all field stations. It will transmit the parameters describing the trajectory and the predicted location of the capsule. During re-entry, it will provide and transmit to the control center at Cape Canaveral a continuous prediction of the landing point on essentially a real time basis (Reference 26). During the flight a Recovery Officer or Supervisor will continuously monitor the predicted impact areas from a control station within the main control room and supply information to the group which will conduct the search and recovery operations. It is assumed that this group will be made up of representatives of the NASA and the various organizations which have contributed forces to this operation, such as the Air Force and the Navy.

Arrangements should be made for alerting the Coast Guard, ARS, CAP, FAA, FCC, Forestry Service, and other official and civil groups (Reference 18).

It is expected that information regarding capsule beacon frequencies, progress of preparations, hold-fires, postponements, launchings and flight progress will be relayed from the control center and communications center by appropriate means (see next section) to the local commanders who are responsible for the ships and aircraft covering their particular impact areas. These local commanders should be designated according to their overall effectiveness in handling communications, their navigational accuracies, and ability to direct the local search and recovery operation. In increasing order of preference, vehicles for this CIC function would be fixed-wing aircraft, airship, and surface ship, with the possibility of a land-based installation being best when it is in close proximity to a particular landing area.

The local commander would be responsible for maintaining a plot of the impact point predicted at the main control center, together with any sightings during re-entry, descent or after landing made from local craft within his or neighboring areas or from any DF stations including Navy SOFAR indications. He would relay all appropriate information to the vehicles under his command and keep the main control center advised on progress. If the capsule passed by without landing he would reposition his forces, when possible, to cover another possible landing area for a subsequent orbit. He would designate search patterns and assist aircraft, if necessary, with navigational checks. He may designate an On-Scene-Commander and request additional vehicles or facilities. Each local commander should have meteorologists to assist in the recording and forecasting of local weather and sea conditions and should relay this information to the control center at Canaveral for use in the scheduling or delaying of the launch.

COMMUNICATIONS

In general the communications capabilities of the ships and aircraft of the U.S. Navy, which are suitable for the job of locating and retrieving the Mercury capsule, are quite satisfactory for the task. However, to insure the best possible naval communications, two recommendations are made: that NASA request

1) that ships with the latest communication equipment be assigned to the Mercury recovery task force or that the latest equipment be put aboard the ships assigned,

2) that well qualified technicians adjust and maintain at peak performance whatever equipment is aboard.

For convenience of discussion, the communications requirements for Mercury recovery are divided by geography and nature of the terminals into the four groups below:

A) Tracking Network Communications
B) Communications Between Shore and Recovery Forces
C) Communications Between Capsule and Recovery Forces
D) Communications Among Vehicles in the Recovery Forces

A. Tracking Network Communications

The communications network for the "tracking and ground instrumentation system for Project Mercury" is covered by NASA Specification S-45 (Ref. 26), paragraphs 4.1.4 and 4.2.4, and is discussed here only for the sake of completeness. It is understood that capsule position information, certain telemetered data and in some cases voice will be transmitted on a real time basis to the communications and computing center at Beltsville, Md., and the control center at Cape Canaveral, Fla. It is assumed that certain of this information, after editing and computing, will be relayed to the recovery task force along with other data generated at the control or computing center. In particular, it is believed that during insertion into orbit and during re-entry, tracking data will be used to make impact point predictions and that these, on a real time basis, will be transmitted to the recovery vehicles to provide early warning before impact and a final fix afterwards.

B. Communications Between Shore and Recovery Forces

Information generated at the command and computing centers for relay to recovery vehicles in the North Atlantic can probably best be handled by Navy FOX broadcasts.* The FOX transmitters located in the vicinity of Washington, D.C., and Panama use

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* Naval communications are emphasized here because ships and aircraft of the U.S. Navy are appropriate as the primary means of detecting the capsule and effecting recovery in the high probability areas of the Atlantic. However, the other military services, the U.S. Coast Guard, Federal Aviation Administration, and certain commercial communication companies have networks which could back up or augment the Navy's communication system (Ref. 18).

various low and high frequencies to cover different parts of the Atlantic. Reliability of this system is very good, being a function of the individual vehicles equipment, the shifting of the reflecting layers of the ionosphere, and the vagaries of magnetic storms.

NASA should request that the Navy assign to the recovery task ships with the latest single side band (SSB) communications equipment, or that the Bureau of Ships be authorized to install such equipment on the ships assigned. NASA should also request that whatever equipment is used be adjusted to optimum performance before assignment to the task force, and maintained in that condition.

The shifts in the ionosphere occur primarily during sunrise and sunset as the air warms and cools and hence changes density and height. Thus, critical periods of communications should be avoided, other factors being equal, during sunrise and sunset.

In regions where the HF ground and sky waves are nearly equal, at about a few hundred miles from the transmitter, fading or interference sometimes occurs, but such regions do not include the normal recovery areas.

Since many forms of communications will be affected by magnetic storms, it is assumed that the Mercury capsule would not be launched at a time when such storms are anticipated.

It is assumed that the type of information to be transmitted to the recovery forces would be capsule position and impact point predictions, time of various events in the launch and re-entry sequence, and general comments on the operation, all of which could be sent by teletype message or coding and decoding Morse code.

As a means of assuring the most reliable communications, regular FOX broadcasts (silent periods not to exceed a few minutes duration) for some stated period (perhaps a few hours) prior to launch and thereafter until impact, should be made so that each ship's radio watch can monitor for equipment performance and for the most suitable receiving frequency.

Messages which would be transmitted ship to shore would include position and readiness of the ship and any vehicles under the command of that ship, the sighting of the capsule or messages received from it during insertion, orbit or re-entry, the detection and recovery of the capsule and the state of the astronaut. Since shore-based receiving channels are limited, it is recommended that frequencies be allocated and a reporting sequence established to guarantee maximum reliability. The particular arrangements would presumably be recommended by Navy Operations personnel to NASA after the requirements have been determined. Frequency allocations beyond those already assigned for Navy use would be subject to FCC rulings. Certain aircraft in the recovery force having suitable HF receivers, as AN/ARC-38, could receive the Morse code transmissions from FOX also.

C. Communications Between Capsule and Recovery Forces

The UHF radio (298.6 Mcps) and the HF radio (15 to 18 Mcps) aboard the capsule should be receivable by all naval vessels. All aircraft can receive on UHF and many on HF. Transmitting facilities are correspondingly available. A listing of the communications equipment in the capsule is given in Table 6 , a list of aircraft and ship communications equipment is given in Tables 11 & 12, and maximum communicating ranges to aircraft are given in Table 13. The UHF ranges in Table 13 will be less where the horizon becomes the limiting factor, in which case Figure 7 may be used to estimate range from the effective antenna heights.

Certain rules should be established regarding the times during which recovery forces may attempt to transmit to the astronaut, and which vehicles in a given recovery areas should have priority, in order to minimize interference at the capsule's receiver. Such rules might be (1) no transmissions during insertion and orbit, (2) when it is known at the command center in which recovery area the capsule will land, the command center should authorize the commander of the area's recovery forces to attempt communications with the astronaut, (3) the area commander if several vehicles are in his command, should direct in what sequence they should attempt communication depending upon their altitude and proximity to the capsule, (4) when it is not known at the command center in which area the capsule has landed, the command center may assign a sequence for attempting communication, or it may authorize communication by any area commander whose vehicles can detect any of the capsule's recovery aids.

D. Communications Among Vehicles in the Recovery Forces

Ship to ship communication is generally by HF radio.

The ground wave of a ship's HF radio will carry 150 to 300 miles (61) under normal weather conditions. The lower limit applies to the standard radio in "average" condition. If the radio is in "peak" condition, the upper limit is applicable. The latest SSB equipment would easily reach the upper limit. Beyond the limit of a strong ground wave, and before the reception of a strong sky wave, a dead zone or an interference zone may occur depending upon frequency and time of day. If direct communication between two ships is not possible, then another ship or a shore station can almost always be used as a relay point with possibly some delay. Basic fleet operational communication doctrine is discussed in Reference 63 and is supported and amplified in References 64-66.

Normal ship-aircraft communications is by voice over UHF radio. Since UHF is line of sight, aircraft altitude will be the primary limit. Distances of 200 miles should be possible, depending upon the ship's antenna installation, for altitudes of 20,000 feet or higher. Figure 7 permits estimates for lower altitudes.

UHF radio voice is also used for air to air communication. Ranges up to 200 miles may be possible under favorable conditions unless both aircraft are flying low. Consult Figure 7 .

TABLE 13

MAXIMUM COMMUNICATIONS RANGES FROM CAPSULE VOICE LINKS

From	Using Antenna	To	Range (Naut.Mi.)
UHF trans/recv.	Biconical Horn (BH)	Aircraft with ARC-27 or ARC-52	100
"	Descent/Recovery (D/R)	"	140
UHF trans/recv. (recovery/backup)	BH	"	50
"	D/R	"	70
HF trans/recv.	BH	Aircraft with ARC-38	2,000
"	Balloon-borne (BB)	"	4,800
HF trans/recv. (recovery/backup)	BB	"	1,500
"	BH	"	700

Notes: (1) Communications in the opposite direction should be equal to or greater than those shown. Ranges have not been calculated since the capsule's receiver sensitivities are not known. However, it is believed that the additional transmitted power of the recovery vehicles should overcome any lower receiver sensitivity in the capsule.

(2) Aircraft with ARC-2 HF transmitter/receiver cannot receive the capsule's voice transmissions since ARC-2 receiving band is 2 - 9.05 Mcps.

(3) Ships' receiving range for UHF voice should be greater than aircrafts' because of improved antenna system, but line-of-sight restrictions will be greater.

(4) HF receiving range for ships should be greater than for aircraft because of improved antennas, but in both cases, at over-the-horizon distances consideration must be given to the relative effects of ground and sky waves.

NAVIGATION

Navigation as used in this section refers to the ability to determine the position of a vehicle in the latitude-longitude coordinate system of the earth. It is assumed that the position of the capsule during flight and the predicted and measured impact points will be reported to the local recovery forces in the lat-long system. The total uncertainty of the capsule's position relative to a recovery vehicle will be the combined errors of the reported position and the navigation system.

In the event that an aircraft detects the capsule and reports the position to a retrieving vehicle, the error in capsule position with respect to the latter will include both vehicles' navigational errors. Thus, navigational errors should be kept as small as possible in order to minimize search time.

Three systems of navigation are currently used at sea. One, based on direction finding from the stars, is called celestial navigation. A second, commonly known as LORAN, utilizes the time difference of a signal from two known radio transmitters. The third, which requires sounding of the ocean bottom, establishes position with respect to known contours of ocean depth.

Celestial navigation, it is generally agreed, is accurate to within two miles; many mariners claim one mile. Between star sightings, dead reckoning from compass, speed and wind indications updates position. Errors accumulated from dead reckoning depend upon the weather, the current and errors in compass and speed indicator. By the use of charts of ocean currents, dead reckoned positions can be corrected to give estimated positions, the errors in which could probably be kept to 0.5 miles per hour under average sea conditions.

Not all small aircraft are equipped with canopies or viewing ports to take the necessary star sights. Wind is the major source of uncertainty in aircraft dead reckoning. Where a doppler navigator is available, ground track and speed can be directly determined. Where it is not, charts of the average winds and local meteorological data are used.

LORAN coverage (Reference 67) for the North Atlantic on which Mercury's orbits have been superimposed is shown in Figure 26 . The areas shaded dark grey represent regions where ground wave (day and night) lines of position have an average error of one mile or less. Areas shaded light grey show regions where sky wave (night only) lines of position have an average error of two miles or less. Comparing Mercury's first three paths across the Atlantic with the shaded areas indicates three roughly equal distances with one-mile, two-mile, and poor LORAN coverage, respectively.

LORAN receivers (DAS series equipment or equivalent - see Table 12) are carried aboard all ships. Airborne LORAN sets (AN/APN-4 or APN-70) are aboard most aircraft considered for Mercury recovery. Airborne equipment list, Table 11 shows which aircraft have LORAN capability.

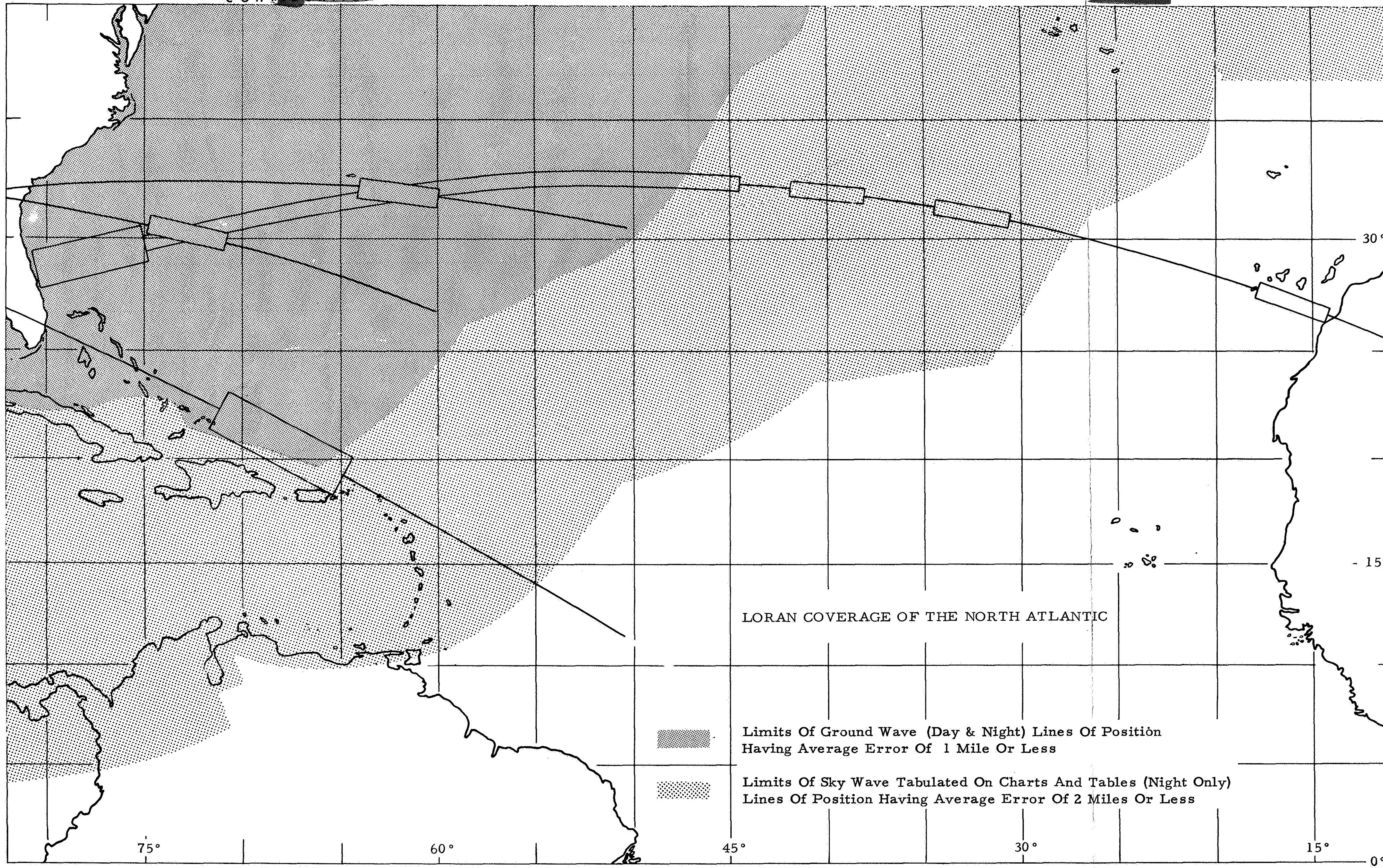

LORAN COVERAGE OF THE NORTH ATLANTIC
Limits Of Ground Wave (Day & Night) Lines Of Position
Having Average Error Of 1 Mile Or Less
Limits Of Sky Wave Tabulated On Charts And Tables (Night Only)
Lines Of Position Having Average Error Of 2 Miles Or Less
75°
60°
45°
30°
15°
30°
15°
0°

FIG. 26

Ocean bottom sounding, available to ships only, permits the navigator to establish on which contour of a sounding chart his ship is located. Sounding is generally less accurate than the other means of navigation due largely to limitations in ocean bottom charting.

Short range systems are also used for aircraft homing. TACAN is widely used for ranges of less than 200 miles. All carriers and certain other ships carry TACAN transmitters (as URN-3). TACAN includes distance measuring equipment, so that bearing and range may be obtained with respect to the transmitter. If the ship relays its position to the aircraft, then the aircraft is fixed within the errors of TACAN (3/4°, less than 1 mile) and the ship.

Radio compasses, providing bearing only, found on most aircraft can be used out to 150 miles from the low frequency transmitters.

Inertial Navigation systems which can maintain extreme accuracy for many hours are becoming available to ships and aircraft. It is not expected that such systems will be aboard the vehicles used in the Mercury program.

In areas of satisfactory LORAN coverage or in weather permitting frequent star sighting, navigational errors should not exceed two miles. Since this error is small compared to uncertainties in the predicted impact point or the sweep widths involved in detecting the capsule after impact, it is concluded that navigational errors should not add to the retrieval time of the capsule.

RELIABILITY

Performance, reliability, access time and cost are considered in this study to be the major parameters which determine the operational effectiveness of a recovery system. In order to maximize effectiveness, it must be possible to measure and evaluate the effect of each of these parameters on the ability of the system to recover the capsule.

With this objective in mind, an attempt is made to provide a measurement of recovery vehicle and equipment reliability and show how these interact to add or detract from the effectiveness of the recovery operation. All of the functions and equipments involved in each phase of operation are identified in a functional block diagram in Figure 27. The block diagram shows all the combinations of recovery modes which are likely to occur. By tracing any mode path from left to right, the specific individual functions, vehicles, and equipment essential to the successful achievement of recovery are identified. The results of a reliability evaluation of each of these items are summarized in Table 14.

The capsule detection and search operations of recovery, shown in block diagram form in Figure 29, are the most critical from a reliability viewpoint. The functional diagram indicates that the capsule can be detected by numerous detection devices, and the probability of at least one of these operating successfully is extremely high. Obviously, however, reliability without consideration of performance cannot be used to appraise the full value of each equipment. Reliability parameters for the various detection, homing and communication equipments are determined in this section. The effectiveness of the detection equipments including reliability and performance considerations is evaluated in a subsequent section entitled "Operational Effectiveness".

Vehicle Flight Availability

Flight availability is defined in this study as the probability that a vehicle will be operable at the beginning of its mission. It is a function of the frequency of repairs, other maintenance actions, and the efficiency of the maintenance and support system.

If it is assumed that the military services will allocate for the Mercury recovery operation vehicles from among those which are already "in commission" on the launch date, flight availability will be 100% and no problem. In the case of ships, it is assumed that this will be the situation and no attempt is made to obtain service availability data for this study.

Regarding airborne vehicles, however, it is possible that groups of aircraft may be assigned to this project but continue to operate in service up to the date of deployment on station. In this event, spare aircraft would have to be assigned to assure a high probability of having a given number available.

Average availability factors for aircraft, airships, and helicopters appear in Table 15. All but the H-21 availability values were based on one month of

FIG. 27

OVERALL RECOVERY FUNCTIONAL DIAGRAM

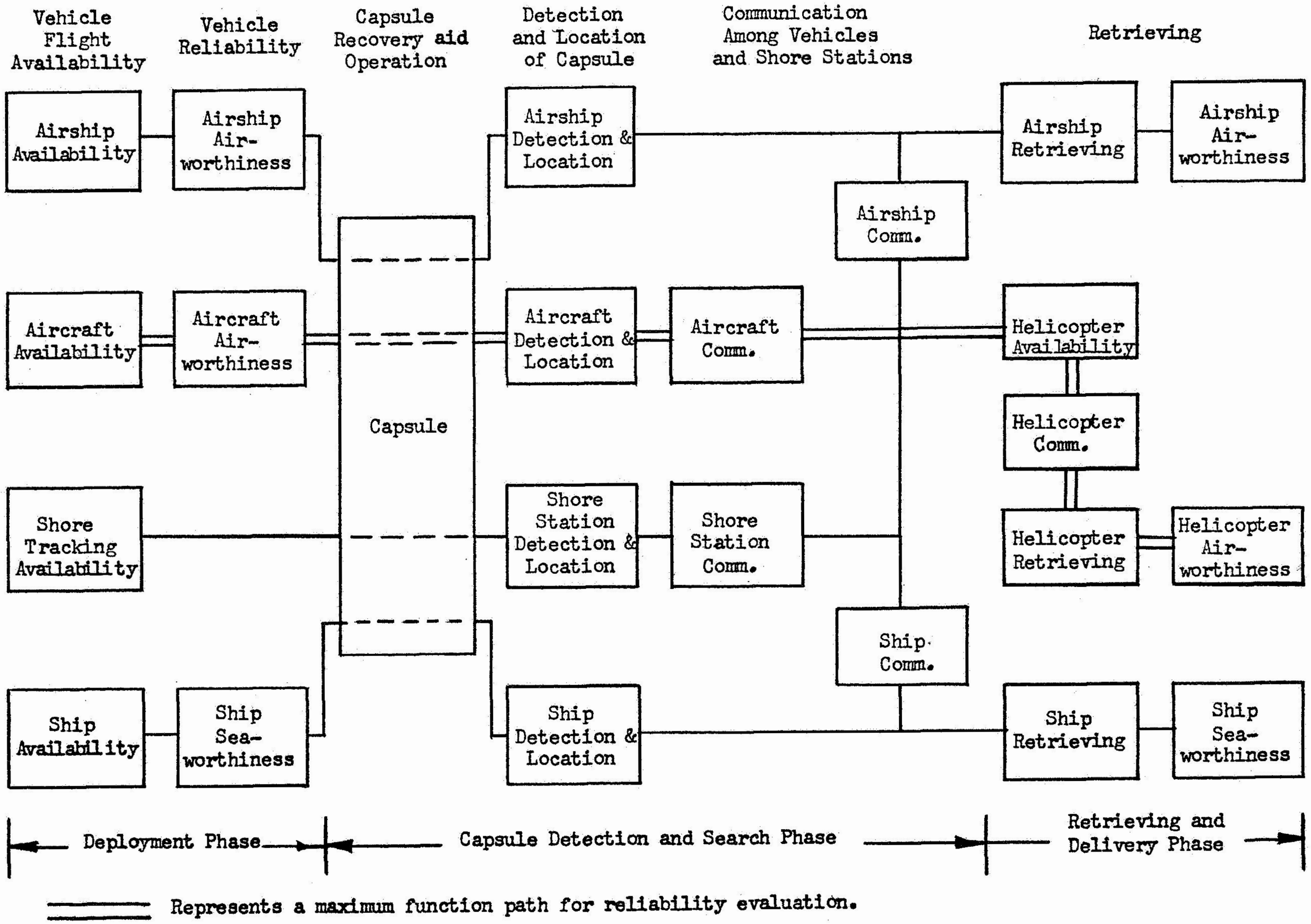


TABLE 14

RELIABILITY EVALUATION SUMMARY

Recovery Phase	Function or Equipment	Minimum Assessed Reliability Under Conditions Noted	RESULTS	Text Reference
DEPLOYMENT	Vehicle Flight Availability	Minimum Flight Availability Depends on No. of Spares Assigned	1. Flight availability factors for air vehicles range from 46% to 87% according to a sample of Navy operational data. 2. Plots are developed to show the number of spare aircraft required to assure various probabilities of having the required number of available aircraft for staging and deployment.	Table 15 Figure 28
	Vehicle Reliability	.996 (Reliability of WV-2 on 6 hour flight to station)	1. Estimated abort rates for aircraft range from 1 to 20 per 10,000 flight-hours based on accident statistics. 2. Absolute values are all too low to receive consideration in selection of vehicles for recovery operations. Rates are of interest in estimating vehicle accidents and losses in a given recovery operation. 3. Ship reliability (seaworthiness) is considered to be 100% for all practical purposes.	Table 16 Table 16 Page 101
CAPSULE DETECTION AND SEARCH	Capsule Recovery Aids	Assume All Capsule Aids Failed	1. Numerical assessment of reliability is not attempted in this study due to lack of empirical data. 2. Failure effect analysis of present capsule recovery aid operating functions indicates two areas recommended for more detailed scrutiny. (a) Switch-over from main to descent antenna, single failure of which appears to cause loss of all UHF transmission. (b) Intentional switching off of C&S band beacons upon capsule impact. This action eliminates a major direction finding capability among search aircraft.	Page 101 Page 103
	Detection and Homing Equipment Reliability	.93 (Probability of Airborne radar operating 1/2 hour before impact and 1 hour during water search)	1. Present aircraft have two or three of the following primary electronic detection and direction finding methods: Radar, ECM homing, and UHF homing. 2. The probability of at least one of these operating on an aircraft following 1/2 hour equipment warm-up and check-out or travel to station is at least .9997. Evaluation, to be complete, considers equipment effectivness: probability of equipment operating (reliability) x probability of detection (performance). 3. Assuming the most critical condition, i.e., all capsule aids not working, the only remaining electronic detection aid is radar. It is the least reliable of detection equipments, and has a .976 probability of operating after 1/2 hour operation. After an additional hour of search operation, the probability of operation is .93. 4. Shipborne directional finding equipment is essentially limited to radar, which is more reliable than aircraft radar. Only a few ships have ECM and UHF homing equipment.	Page 103 Figure 30 Also see Table 30 Figure 30 Table 19
	Communication Among Vehicles and Shore Station	.994 (Probability of HF communications operating after 1-1/2 hours)	1. All vehicles, ships and aircraft have both UHF and HF communication equipment. The probability of at least one equipment operating on an aircraft following 1/2 hour equipment warm-up and check-out on travel to station is at least .9999. 2. Shipborne communication equipment is slightly more reliable than corresponding aircraft equipment.	Figure 30 Table 19
RETRIEVING	Capsule Retrieving	.994 (Reliability of an HR2S on a 3 hour flight)	1. Reliability evaluation of the retrieving operation is not attempted in this study due to lack of empirical data. 2. Reliability of this phase is dependent on the same parameters of the Deployment Phase: vehicle flight availability and sea and airworthiness. 3. Because of the high abort rate of some helicopters, consideration must be given to operating them in pairs as retrieving vehicles.	Page 107 Tables 15 and 16 Page 107
Typical Recovery Operation shown in Figure 27.		.92	Minimum probability of an aircraft reaching station without incident, airborne radar and HF communication equipment operating for 1-1/2 hours, and retrieving helicopter making a 3-hour flight without incident.	

operation as reported by CNO in Reference (37). Although the sample size is small, the data are indicative of the range and relative values of operational availability that one might expect from the variety of air vehicles presented.

For the recovery operation, it is anticipated that maintenance effort will be increased to assure maximum availability. An example of this was recently given in Reference (38) wherein it was reported that a squadron of S2F aircraft maintained an availability of 73% around the clock. On the basis of this example, the availability of all the vehicles was upgraded and grouped into three availability levels as indicated in Table 15.

Using these three levels of availability, the probability of having at least 1,2,3 ...... n aircraft available among N inventory aircraft is given by the following binominal function and plotted in Figure 28.

$$P(n) = \sum_{i=n}^{N} \frac{N!}{i\,!\,(N-i)!} \; p^{i} \; q^{N=1} \quad \text{where:} \qquad \text{(Equation 15)}$$

$P(n)$ = the probability of at least n available among N aircraft.

$\frac{N!}{i!\,(N-1)!}$ = the number of combinations involving i available among N aircraft.

N = Number of aircraft on hand.
n = Number of available aircraft.
p = Probability of an aircraft being available.
q = 1 - p = probability of an aircraft being unavailable.

The example in Figure 28 indicates that at a 55% availability level, 8 aircraft are required to assure a 90% probability of having 3 ready to fly at any time. Although aircraft flight availability factors may not be precisely as presented, the plots serve as a guide in determining the number of aircraft required to carry out a given staging plan.

Vehicle Airworthiness

Since reliability is the probability that a vehicle will operate satisfactorily for a given time, the intended purpose of the vehicle in the recovery operation must be established in order to judge "satisfactory performance". Accomplishment of the mission involves several distinct functions which are divided into two categories:

1. Those involving the integrity of the vehicle as an equipment carrier such as flight control, structure, and propulsion systems.

2. Those provided by the equipments essential to the ultimate accomplishment of the mission. These include capsule detection, location, communication, and retrieving gear. (These functions are discussed separately in subsequent sections.)

PROBABILITY OF AT LEAST n AIRCRAFT BEING AVAILABLE AMONG N ON HAND

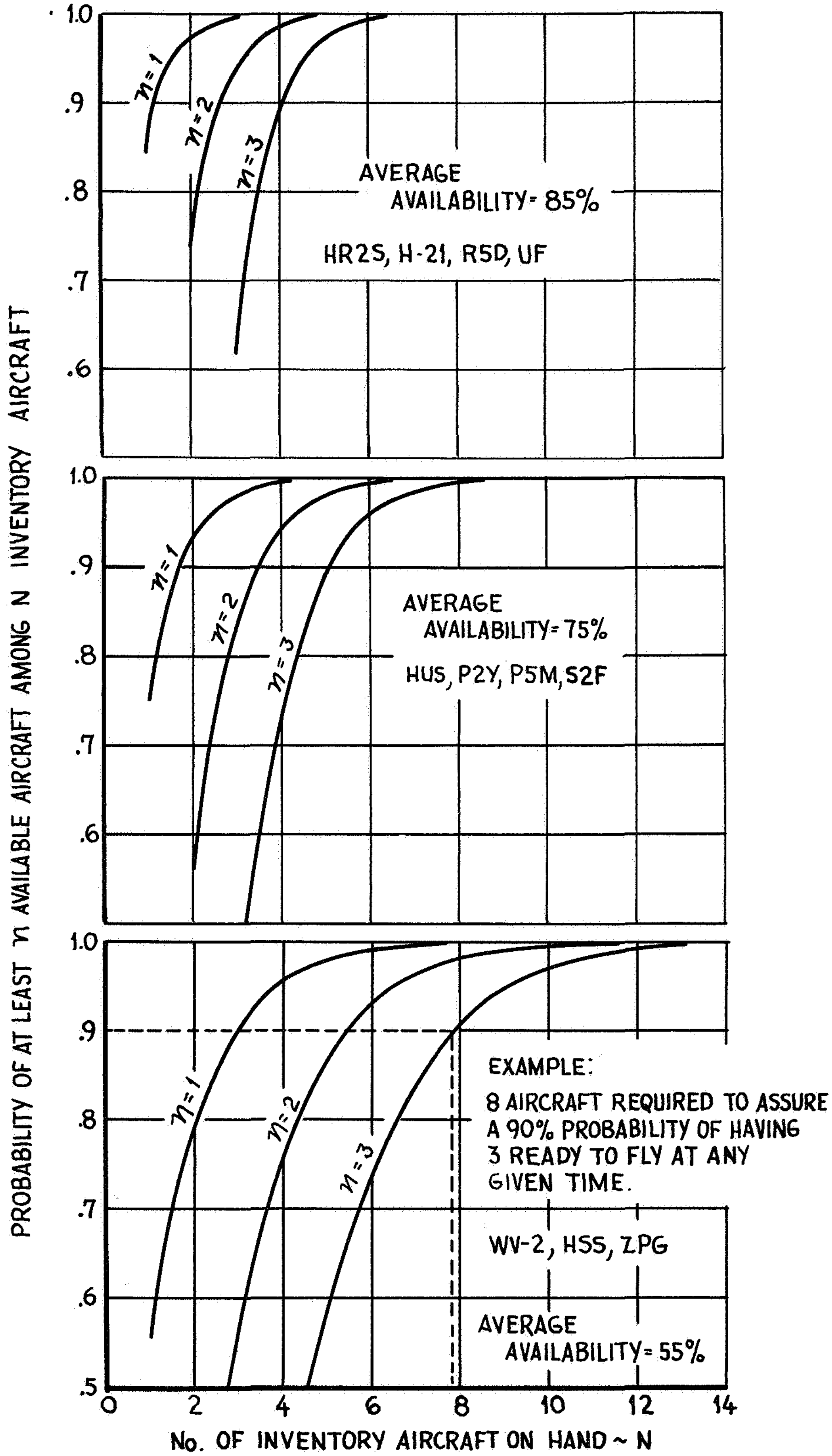


FIG. 28

AIRBORNE VEHICLE FLIGHT AVAILABILITY FACTORS

Vehicle Type	Model	(1) Average Availability % of Inventory Aircraft in a Flyable Condition	Estimated Availability with Increased Maintenance Effort (4)	Group Availability Level For Calculation Purposes
Helicopter	HR2S	86.5	87 (5)	85
Helicopter	H-21	84.0 (2)	84 (5)	
Aircraft	R5D	77.5	89	
Aircraft	UF	72.0	82	
Helicopter	HUS	68.0 (3)	78	75
Aircraft	P2V	67.8	77	
Aircraft	P5M	64.2	73	
Aircraft	S2F	64.0	73	
Aircraft	WV-2	51.1	58	55
Helicopter	HSS	50.8	58	
Airship	ZPG-1,2,2W	45.6	52	

(1) Availability figures, except (2) and (3), are from reference 37.
(2) Obtained from Vertol Service Department (G. Cucore, 7/9/59 phone message) based on 130-150 hours of airways flying/month.
(3) Represents availability for HU class. HUS data not available.
(4) Column 3 figure x 73/64, the ratio of maximum maintenance effort availability to normal effort availability obtained during S2F operations, reference 38.
(5) Estimated to be maximum effort availability.

TABLE 16 - ESTIMATED ACCIDENT AND MISSION ABORT RATES FOR AIRBORNE VEHICLES

(Table Arranged with Lowest Abort Rate at Top)

Type and Model	Accidents and FLIGA's [1] Per 10,000 Hrs[3]				Estimated Relative Mission Abort Rates Col. A & B
	Accident Rates		FLIGA Rates		
	Total	Mission [2] Abort Type Accidents Col.A	Total	Mission[2] Abort Type FLIGA's Col.B	
Airship ZPG-1/2/2N	2.8	0	10.4	1.0	1.0
Aircraft R5D	0.3	0.2	2.3	1.0	1.2
Aircraft UF	0.9	0.9	5.0	2.0	2.9
Aircraft P2V-5/7	0.7	0.4	7.2	3.3	3.7
Aircraft S2F	1.6	0.5	9.1	3.7	4.2
Helicopter HUS	1.7	0.4	9.9	3.9	4.3
Aircraft P5M	2.6	1.7	14.3	5.1	6.8
Helicopter HSS	1.7	1.3	17.6	5.9	7.2
Aircraft WV-2	0.9	0.8	13.7	6.7	7.5
Helicopter HR2S	9.2	3.7	52.0	16.5	20.2
Helicopter H-21	3.2[4]	-	-	-	-

(1) FLIGA - Forced Landing, Incident, or Ground Accidents. Reference 35.

(2) Phases of operation included in abort type accidents and FLIGA's are: Take-off, Flight, and Auto-Rotation (Helicopters only).

(3) Reference 41.

(4) Reference 42.

Accident and Forced Landings, Incident, and Ground Accident (FLIGA) statistics provide a good yardstick for determining the relative frequency of expected occurrences which might result in failure to accomplish the mission due to material deficiencies or other reasons. Accidents and FLIGA's per 10,000 flight hours compiled in Reference (41) by the U.S. Naval Safety Center are listed in Table 16 for applicable aircraft models.

From these data, mission abort rates are estimated by omitting those accidents and incidents occurring during static, taxi, wave-off, and landing phases of operation. Not included, however, are intentional aborts which avoid accident, forced landing or incident. Even considering these additional incidents, the frequency of aborts is not expected to appreciably influence the recovery operation when considering the low flight time per aircraft. For example, using the maximum abort rate, 20.2 per 10,000 hours for the HR2S helicopter, and a maximum mission of 3 hours, the probability of no abort is .994.

For the WV-2 on a 6 hour mission, the probability of no abort is - 1 - .00075x6 or .996.

Ship Seaworthiness

The abort rate for a ship should be much lower for airborne vehicles and therefore is not analyzed further for the purpose of this study.

Capsule Recovery Aids

At present there are few or no empirical data on capsule recovery aids on which to base a quantitative assessment of reliability. As an alternative, this study is conducted on the assumption of various combinations of capsule aids operating or not operating. Possible combinations of capsule aid failures are determined from a review of all available design information on the functional arrangement of the recovery equipment. For example, failure of a single antenna or switch might result in loss of all HF and UHF transmission.

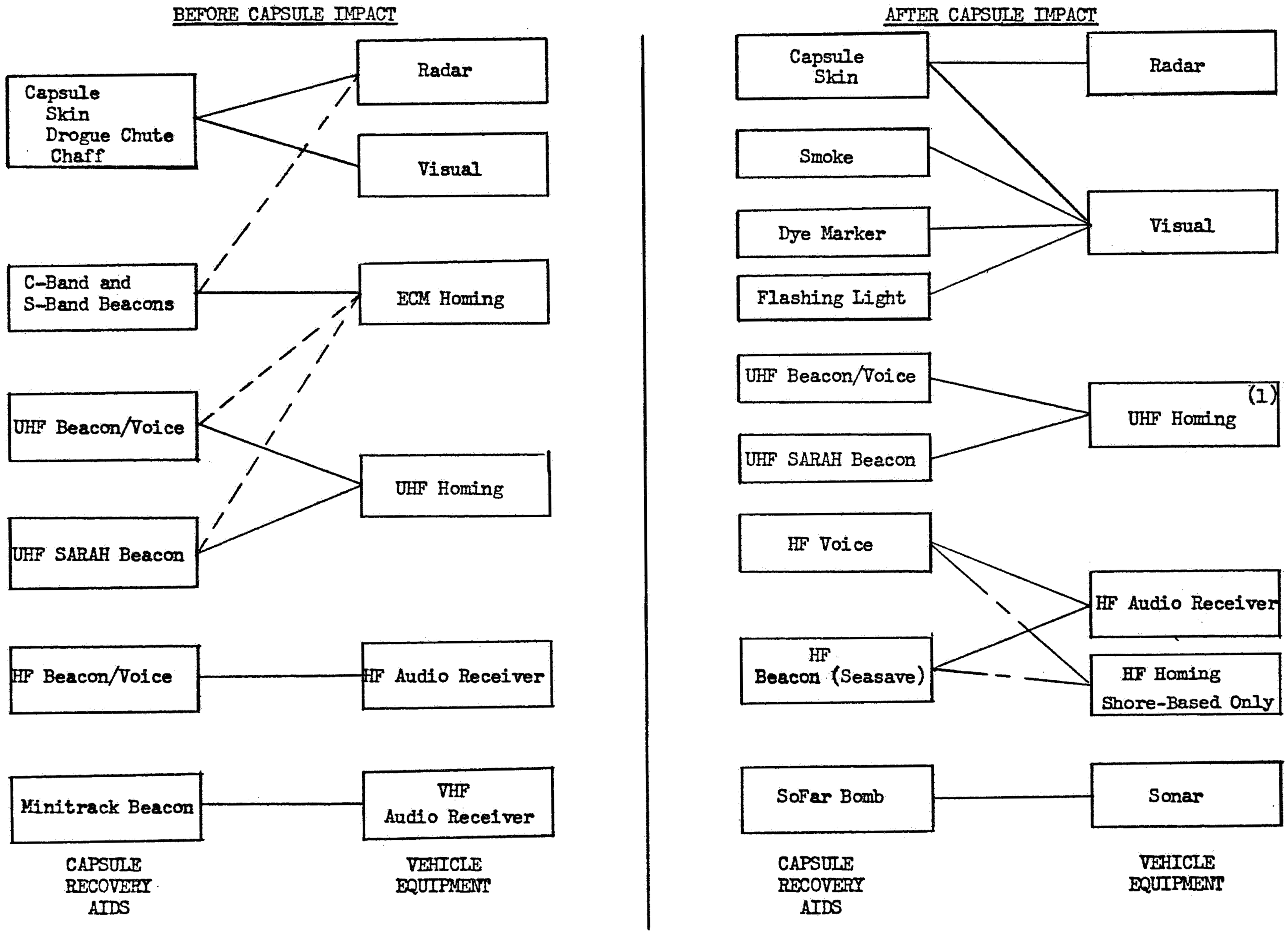
A cursory failure effect analysis of the capsule recovery system design indicates that considerable emphasis has been placed on assuring redundant paths for the operation of the recovery aids. This is particularly true for the electronic recovery aids where redundant circuits with cross-over features have been provided for most equipment. As a result of the failure effect analysis, it appears, however, that two areas might be subject to a more critical review: (1) the switch-over from the main antenna to the descent antenna and (2) the switching off of the C and S band beacons upon capsule impact.

The transfer of UHF transmission from the main to descent antenna appears to be accomplished by a single switch. Should this switch fail, all UHF transmission would be lost including both conventional and Sarah beacons. Loss of the UHF beacons for direction finding coupled with the intentional turning off of the C and S band beacons on impact, leaves only HF transmission among the electronic

Restriction/
Classification
Cancelled

FIGURE 29

FIGURE 29 – CAPSULE DETECTION AND LOCATION – FUNCTIONAL DIAGRAM



NOTE: (1) SARAH receiver required to receive SARAH Beacon unless SARAH Beacon repetition rate is increased to at least 500 cps.
– – – – indicates detection capabilities on minority of aircraft.

aids. Since few aircraft and ships have HF direction finding equipment, electronic homing capabilities after impact would be reduced to skin tracking by radar.

This leads to the second area of concern which involves the switching off of the C and S band beacons. In normal operation direction finding methods after impact, other than visual, are essentially limited to radar and UHF equipments. If switch-over from main to descent antenna fails as mentioned above, only radar homing remains. In this light the advisability of turning off the C and S band beacons is questioned, and it is recommended that NASA arrange for a review of this area and the antenna switching area. It is further recommended (although it most probably has already been done) that a thorough failure effect analysis be conducted on the entire capsule recovery equipment functions in order to assure that the operation of a primary recovery item is not dependent on a single component or function.

It is also advisable to review the results of all testing prior to the manned flight to obtain the latest assessment of recovery equipment reliability. In turn this information should be compared with the assumptions made in this study to check the validity of the results and conclusions.

Airborne Electronic Detection Equipment Reliability

The reliability of this equipment vs. operating time is plotted in Figure 30 . The detection and homing equipment configuration for each of the airborne vehicles is also shown in the figure. Note that while the capsule has a capability of six different electronic direction finding modes, present aircraft can only accommodate a maximum of three. HF and UHF equipment are not included in this category inasmuch as their capability of direction finding by audio means is highly questionable. However, augmented by voice communication with the capsule occupant, these equipments have some value as detection and possibly location aids.

The reliability of the primary detection and homing equipments (radar, ECM homing, and UHF homing) is determined on the basis of mean-time-between-failure (MTBF) data which reflect current operating experience. These data and sources of information are contained in Tables 17 and 18. The reliability plots shown in Figure 30 are derived from the following mathematical expressions.

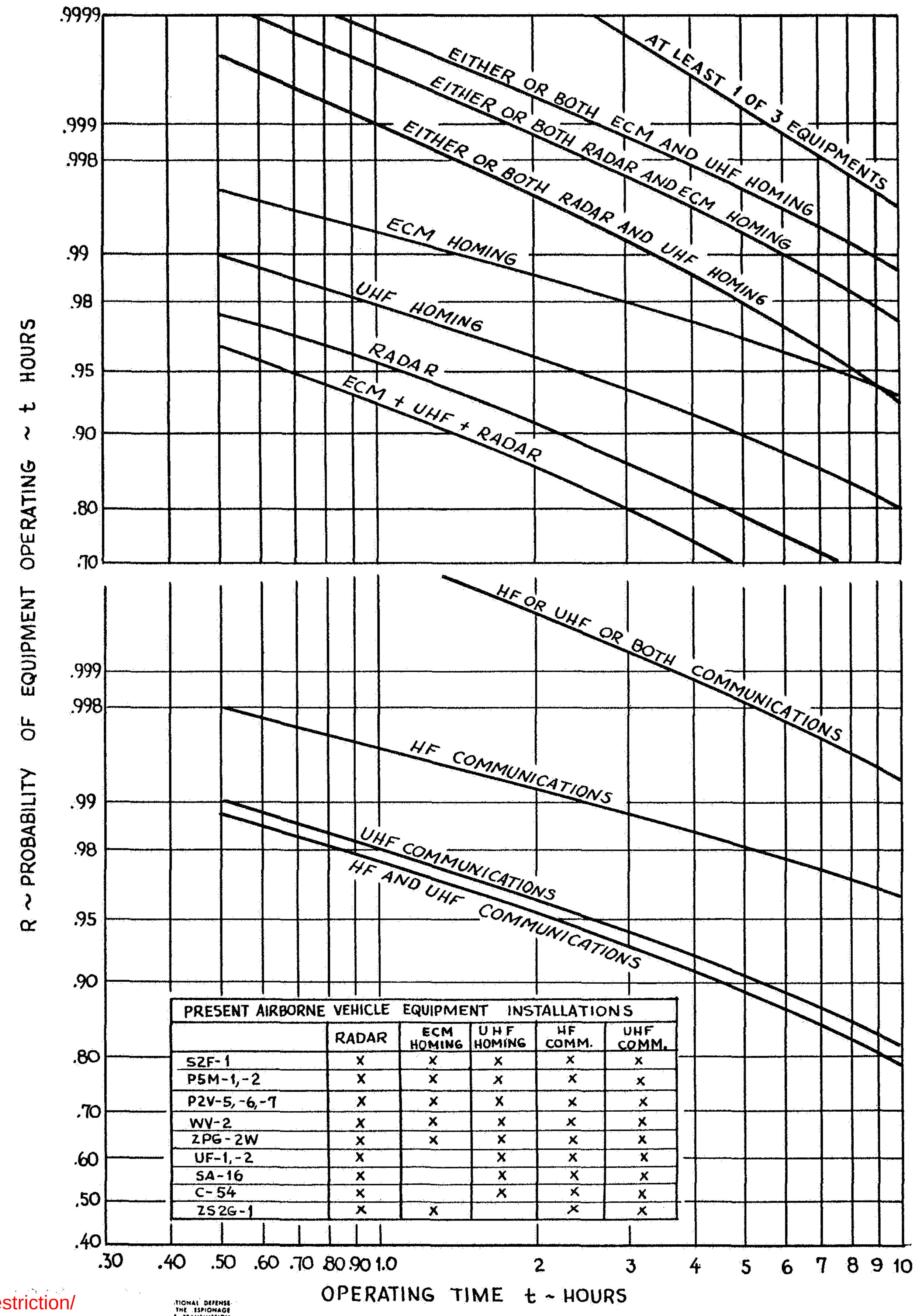
$R = e^{-\frac{t}{T}}$, is the expression for equipment reliability R, in terms of operating time, t and MTBF, T. When two equipments whose reliabilities are R_1 and R_2 are operating simultaneously, the probability R_o, that either or both will be operating after time t is:

$$R_o = 1 - (1-R_1)(1-R_2) \qquad \text{Equation (16)}$$

For three equipments operating simultaneously, the probability of at least one operating after time t is:

$$R_o = 1 - (1-R_1)(1-R_2)(1-R_3) \qquad \text{Equation (17)}$$

RELIABILITY OF AIRBORNE ELECTRONIC EQUIPMENT vs OPERATING TIME



PRESENT AIRBORNE VEHICLE EQUIPMENT INSTALLATIONS

	RADAR	ECM HOMING	UHF HOMING	HF COMM.	UHF COMM.
S2F-1	x	x	x	x	x
P5M-1,-2	x	x	x	x	x
P2V-5,-6,-7	x	x	x	x	x
WV-2	x	x	x	x	x
ZPG-2W	x	x	x	x	x
UF-1,-2	x		x	x	x
SA-16	x		x	x	x
C-54	x		x	x	x
ZS2G-1	x	x		x	x

FIG. 30

For maximum effectiveness in detection before impact, it is desirable to have as many detection equipments operating as practical in the high probability impact areas. It is obvious from Figure 30 that the probability of having at least one equipment operating on any given airborne vehicle is high. It is assumed that regardless of the distance from station, equipments will be turned on $\frac{1}{2}$ hour before arriving on station to allow for warm-up and checkout. For this equipment operating time period, the probability of having at least one operating is greater than .9997. If each of the equipments had equal performance capabilities and all capsule recovery aids worked properly, it could be concluded that there is adequate assurance of having at least one primary electronic detection and homing method available at each station. Since performance capabilities among equipments are unequal, they are analyzed under the most critical situation, i.e., where all electronic capsule recovery aids fail and capsule detection is dependent on radar and/or visual methods.

Figure 30 shows that the probability of search radar being available upon arrival of an aircraft or station following 1/2 hour equipment operating time is .976. Considering that this is an extreme condition which assumes multiple capsule failures and neglects visual capabilities and detection information from other vehicles, the criterion is probably too stringent. To arrive at a more realistic and valid evaluation, equipment reliability and performance must be considered jointly. This is accomplished in the section of this study entitled "Operational Effectiveness" where the effect of this parameter on optimization of vehicle spacing is determined.

For water search after impact, the ECM beacon is no longer on as indicated in Figure 29, and the primary modes of electronic detection are reduced to two, radar and UHF homing. On the other hand, a number of other recovery aids become available to offset the loss of the ECM beacon. These are smoke generators, dye marker, flashing light, HF beacon, and SOFAR bombs.

As was assumed above, the worst condition would be if only radar were available for detection among the prime electronic aids. Under these conditions, the probability of airborne radar operating for a $\frac{1}{2}$ hour warm-up period and an hour of search is .93.

Once impact occurs, however, it is highly probable that the general area would be known either through detection by local vehicles or by ground tracking stations.

If equipment is allowed to remain operating during a hold, reliability decay will occur as shown in Figure 30. To decrease chances of equipment failure, equipment should be turned off if the hold is known in advance to be long. It is believed that holds will present more of a staging problem than a reliability problem.

TABLE 17 – MEAN TIME BETWEEN FAILURES (MTBF) FOR AIRBORNE DETECTION, HOMING, AND COMMUNICATION EQUIPMENT

Function	Equipment: Model	Equipment: MTBF(1) T_i Hours	MTBF for Function, T Where $\frac{1}{T} = \frac{1}{T_1} + \frac{1}{T_2} \cdots \frac{1}{T_i}$
Radar Detection	APS-31, APS-38, or APS-20E	(1)	21 (2)
ECM Homing	APA-69 with	186 (1)	146
	APR-9B	685 (1)	
UHF Homing	ARC-27 with	50 (2)	47
	ARA-25	880 (1)	
HF Homing	Audio Only – Aircraft considered are not equipped with adapters for direction finding except for ARA-8 on some aircraft.		
VHF Homing	Audio Only – Aircraft considered are not equipped with adapters for direction finding except for ARA-8 on some aircraft.		
UHF Communications	ARC-27 or ARC-34	(1)	50 (2)
HF Communications	ARC-2, ARC-8, or ARC-58	(1)	260 (2)
VHF Communications	ARC-1	(1)	200 (2)
Sonar	APR-26	467 (1)	467 (1)

(1) MTBF's from Table 18.

(2) MTBF's are conservatively estimated to be representative of the function shown based on emperical data of Table 18.

Communication Among Vehicles and Ground Stations

The communication among vehicles and shore stations is important for overall coordination of the recovery effort and particularly in the situation where the local area forces must be informed of the predicted impact area or when an aircraft has located the capsule and must transmit this information to the retrieving vehicle. Success of this operation is dependent on the communication equipments operating on both vehicles.

Most aircraft have both HF and UHF communication equipment, and the probability of either or both sets operating is high, as shown in Figure 30. In the worst situation, where an aircraft has located the capsule but cannot communicate, this would not necessarily mean failure of the recovery operation; for the aircraft can drop a sea marker, sonobuoy, etc. and obtain assistance.

The reliability of shipborne communication equipment appears in general to be higher than equivalent airborne equipment. This relationship is expected because shipborne equipment can be heavier and the environments are less severe. Reliability data for shipborne equipment in terms of MTBF are listed with source information in Table 19 . The reliability of this equipment is in no way critical to the recovery operation because (1) most ships have more than two sets of gear and (2) maintenance can be accomplished while underway to maintain a high level of availability.

Retrieve Operations

No attempt is made to numerically assess the reliability of this function as there is relatively little experience in this area and much less empirical reliability data than there is in the other phases of recovery. It is appropriate, however, to point out that for the first time in the recovery cycle, the success of the operation is now dependent on singular functions: one vehicle picking up the capsule and delivering it to the home base. This operation may be particularly critical for the helicopter in view of its having the highest abort rate and (except for the HR2S) its being a single engine vehicle. Back-up may be advisable to cover a possible forced ditching.

Reliability of Electronic Equipment

Reliability is defined as the probability that an equipment will operate satisfactorily under specified conditions for a given time. When failures occur randomly, that is, independent of equipment age, reliability R, can be expressed by the traditional exponential formula:

$$R = e^{-\frac{t}{T}} \quad \text{where:} \qquad \text{Equation (18)}$$

e = 2.71828, the Naperian log base
t = operating time
T = Mean time between failures (MTBF)

TABLE 18

– AIRBORNE ELECTRONIC EQUIPMENT RELIABILITY DATA AND SOURCE

Equipment Group	Description	Model Designation	MEAN TIME BETWEEN FAILURES (MTBF) IN HOURS										
			GAEC (1) Observations		OTHER SOURCES, REFERENCES:								
			S2F	UF	28	29	30	31	32	33	34	35	36
Radio Communications	HF	ARC-2	357	260									
		ARC-8		525									
		ARC-58								167			
	VHF	ARC-1		135	138-295								
	UHF	ARC-27	76	55	51	57				50		24.8	44
		ARC-34					27.4 – 40.3		45				
Detection, Homing, and Direction Finding Equipment	Radar	APS-31		35 (2)									
		APS-38	24 (2)										
		APS-20E						20.9			67		
	ECM Receivers	APA-69	186 (2)										
		APR-9B	685 (2)										
	UHF Homing	ARA-25	880 (2)										
	Sonar	APR-26	467 (2)										
Misc.	Searchlight	AVQ-2A,2C	500 (2)										

(1) Reported MTBF x 50% to correct for incomplete reporting.

(2) Based on ratio of equipment "on" time to aircraft flight time of 1:2.

Thus, if the equipment mean time between failures is known (a convenient reliability index in itself), its reliability can be calculated simply for any given operating time. There are numerous examples of field evaluations of electronic equipment reliability to substantiate the use of equation (18) to mathematically express the reliability of airborne and shipborne equipment. Among these are References (31), (32), (33), (39), and (40) and GAEC's own observations.

Once the failure pattern is established as being random, i.e., failures occurring at a constant failure rate per hour, the mean time between failures, T can be estimated as follows:

$$T = \frac{\text{Total operating time on failed and non-failed equipments}}{\text{No. of failures}}$$

The estimated mean-time-between-failures for the electronic equipment essential to the recovery mission are listed in Table 17. These estimates are based on the substantiating empirical data contained in Table 18 . No attempt is made to associate an MTBF with a specific equipment model since this would imply that MTBF values can be determined accurately with a high degree of confidence. Where a range of values exists for an equipment type, such as HF communication equipment, a conservative value within the range is selected to represent the current "state of the art" for that group. It is important that the relative values among equipment groups be maintained for comparative evaluation purposes. Substantiation of the MTBF values selected to represent equipment groups follows.

For radar, although data are not available for all the radar models installed on the vehicles under consideration, there are sufficient data to indicate a range of values from 21 to 67 hours, MTBF. Both values were determined for the APS-20E radar on the P2V aircraft and ZW-1 airship, respectively. The spread in values can be a result of the differences in definition of a failure and in operating environments. In the former case, a failure was defined by ARINC in Reference (30) as any in-flight or ground malfunction reported by the operator or maintenance man, respectively. The MTBF was computed on the basis of 11,031 "heater hours".

In the latter case, a failure was reported by Goodyear in Reference (34) whenever the airship was forced to leave its station because of unavailability of the radar. Only "on-station" operating time (937 hours) was included in the calculation of MTBF.

From the above, it is concluded that 21 hours and 67 hours are minimum and maximum MTBF values for the APS-20. Other radar MTBF's, 35 hours for the APS-31 and 24 hours for the APS-38 fall within this range. For conservatism, 21 hours are used in all reliability calculations to represent the MTBF for airborne radar.

ECM homing on the majority of vehicles is accomplished by the combination of APA-69 and APR-9B components. Based on 123,096 hours of S2F operation, the MTBF for the combination is estimated to be 146 hours as noted in Table 17.

TABLE 19 - SHIPBORNE ELECTRONIC EQUIPMENT RELIABILITY DATA AND SOURCE								
Equipment Group	Description	Model Designation	Mean Time Between Failures MTBF, In Hours				Average MTBF for Component	Average MTBF For System
			BuShips Data(1)	Other Sources				
Radio Communication	HF	SRR-13 SRR-13A	1740	2022			1881 (T_1)	(2) 245 (T_o)
		SRT-14 SRT-15 URT-4	652 418 136		67	133	281 (T_2)	
	UHF	URR-13 URR-35	696 756				726	166
		TDZ	215				215	
Detection, Homing and Direction Finding Equipment	Radar	SPS-5B SPS-6 SPS-10	354 263 214					277
	ECM Receivers	SLR-2 BLR-1	308 657					482

(1) Reference 46

(2) $\frac{1}{T_o} = \frac{1}{T_1} + \frac{1}{T_2}$

UHF homing is accomplished on the majority of the airborne vehicles by an ARC-27 communication set and an ARA-25 adapter to provide the direction finding function. Table 18 shows excellent correlation among the various sources of data for UHF communication equipment, and 50 hours MTBF is a good representative value for UHF communication equipment. 50 hours combined with 880 hours MTBF for the ARA-25 adapter gives 47 hours MTBF for the combination (Table 17).

There are ample empirical data in Table 18 to indicate that the MTBF of HF communication equipment is several orders of magnitude greater than that of UHF equipment. 260 hours MTBF is considered to be representative of this class of equipment as compared with 50 hours for UHF equipment. Similarly, 200 hours MTBF is representative of VHF equipment.

All available MTBF data on shipborne electronic equipment are compiled in Table 19. Most of the data were obtained directly from BuShips in Reference 46 specifically for this study. The values appearing in the right hand column of the table are estimated to be representative of their corresponding equipment groups. In most cases they represent averages of all the MTBF values in the group.

By comparison of these MTBF values with the MTBF values in Table 17 for corresponding airborne equipments, it is evident that shipborne equipments are more reliable. As indicated previously, the reasons are obvious.

Very little direction finding equipment data are listed in the table because other than radar and SLR-2 or BLR-1 ECM receivers, which are not very effective as direction finders, there is a scarcity of other direction finding equipment among the ships considered for recovery. Inasmuch as ships are not being considered primarily for capsule detection and homing, this factor is of secondary importance.

COSTS

Dollar costs are used in this study to evaluate the relative merits of alternative approaches, systems, and vehicles. Consideration of the dollar costs provides a framework in which the commitment of vehicles, equipment, material, and personnel may be measured in commensurable units. Together with the evaluation of the effectiveness of the system, determination of the cost of its components provides a criterion by which the efficiency of its design may be measured. It will be desirable to distribute the available resources in a manner which insures equal effectiveness throughout; no weak links in the chain are desired. On the other hand, there is nothing to be gained by the excessive allocation of resources to a single element in the system, desirable system redundancies duly considered. Extra-strong links in a chain do not add to its overall strength. Regardless of the level of resources which may be available for the Project Mercury recovery operation, it will be desirable to distribute these forces for maximum effectiveness; regardless of the level of effectiveness chosen, it will be desirable to select forces for minimum cost.

From the standpoint of cost-effectiveness, therefore, the distribution of forces, whatever their availability, should be optimized on a "minimum cost" basis. The "absolute" minimum cost system - that which obtains if the most austere limitations are placed on NASA, given a minimum effectiveness level- is of particular interest for two reasons:

1. For its own sake, as the least expensive system which will do the job, and
2. For its value as a standard by which the additional cost of alternative forces - considered desirable on an intuitive or intangible basis - may be measured.

It would seem, for example, that considerations of national prestige may lead to "over-rescuing" the astronaut (at least the first one) by saturating the probable impact areas with recovery forces regardless of cost.

Should the resources available Project Mercury be changed, knowledge of the minimum cost system provides a guide by which the forces may be replaced or augmented in a manner which will lead to maximum overall system effectiveness. An attempt is made to provide operational cost information in sufficiently general form so that the effect on total system cost resulting from changes in individual elements may be estimated.

Granting then that the minimum cost recovery system is of primary interest, the question remains: minimum from whose standpoint?

The cost of capsule recovery may be evaluated on at least three levels:

1. Actual cost to the taxpayer,
2. Cost to NASA, assuming a short series of tests in which the vehicles and services are provided by other Federal agencies with forces-in-being,
3. Cost to NASA, assuming a continuing series of tests in which the vehicles and services are provided by forces specifically outfitted and manned for this purpose.

Considered on these three levels, the costs of the Project Mercury recovery operation are not the same.

Cost to the Taxpayer. The "actual" cost of the operation will be the expenditure of material and services beyond that which would occur if there were no Project Mercury. This cost includes:

- All development costs
- Cost of additional special equipment unique to this operation
- Cost of fuel, oil, and other consumables beyond that which would normally be expended during this period.

Costs which are not relevant include:

- Personnel costs, since it is not anticipated that military personnel in addition to those already on active duty will be required. ?
- Amortized procurement cost of vehicles or equipment in being.

Presumably it should be the actual cost to the taxpayer which is minimized. Determination of this cost, however, requires that the "normal" operating costs of the agencies involved be known as well as the expected commitment to the capsule recovery program. Since this involves consideration of the disposition of forces in the field prior to the recovery, and other information of a nebulous and perhaps highly classified nature, it is not considered that this cost can be practically determined within the scope of this study.

Cost to NASA Using Existing Facilities. Inasmuch as the recovery operations for the short series of tests planned are expected to be provided by the forces-in-being of other Federal agencies, the direct costs incurred by these forces provide another basis for measuring the expense of the recovery operations. These provide an indication of the actual commitment of these forces and should be useful in evaluating one system involving different numbers and kinds of aircraft, ships and personnel with another. In addition, these costs represent the maximum amount which NASA might reasonably be billed by other agencies.* They include:

- Cost of fuel, oil, and other consumables directly chargeable to the operation
- An apportioned share of the maintenance required for the continued operation of the ships and aircraft used
- Pay and allowances of personnel directly involved in the recovery ?
- Cost of special equipment unique to this operation
- Cost of special training
- Development costs

*This discussion is not intended to define what is or is not appropriate for other Federal agencies to actually charge NASA for the recovery operation. The costs enumerated are intended to provide a reasonable basis for comparing one system with another or one vehicle with another. The matter of the apportionment of Federal costs among the several government agencies for services rendered to the public is certainly not within the scope of this study.

No attempt is made to evaluate quantitatively the cost of special training or development costs. With the exception of the cost of special equipment, the remainder are vehicle costs which vary directly with operating time.

It is anticipated that these operating costs will be the major expenses incurred in the recovery program. They will be used as the primary basis for comparing vehicles and systems in this study.

Cost to NASA of Future Tests. To provide for continuing orbital tests, it may be necessary to establish facilities whose primary function will be the recovery of orbital vehicles, such as those operating from Cape Canaveral and the Pacific Missile Range. The elements of cost which would be encountered in this event would include, in addition to the direct operational costs described above, the cost of procuring and possibly refitting ships and aircraft. Personnel costs for civilian crews would be different from those of military crews.* Since it is not a primary purpose of this study to select vehicles or recommend a system for continuing operations, however, these costs will not be evaluated in this study.

Conceivably, the selection of vehicles and systems might vary with the cost standard chosen. This is not necessarily the case, however. Large ships generally cost more to procure or refit, require larger crews, and burn more fuel than small ones. It is expected that direct operating cost to the cognizant agency provides a reasonable basis for the selection of vehicles, and that the choice of vehicles would not be substantially different using either of the other standards mentioned.

Cost of Staging and Recycling. The principal operational costs are those incurred in staging the detection and retrieval forces and recycling them to their stations in the high-probability impact areas as required until the Mercury capsule is successfully launched and recovered. The operating costs of feasible ships and aircraft are examined so that their alternative costs as detection and retrieving vehicles may be evaluated. The costs do not take into account differences in reliability, availability and accident rate among the models considered.

The following discussion of operational costs consists of four principal parts:

1. Operational unit costs are developed for the ships and aircraft of interest.
2. Helicopters, airships and several types of surface ships are evaluated as retrieving vehicles.
3. Several models of aircraft are evaluated as detection vehicles.
4. The effect of changes in total recovery system cost resulting from varying numbers of detection and retrieving vehicles is considered.

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*Data on labor rates for civilian marine personnel are given in References 51 and 52.

Operational Unit Costs

Direct costs per hour of operation are presented for aircraft in Table 20 and ships in Table 21 . The cost of Navy vessels is drawn from the best available data which are given in the form of annual operating costs. These are reduced to cost per hour of operation on the basis of the average number of hours underway per year for the particular type of vessel, as described below. Hourly costs for aircraft have been sythesized from available data on the principal components of direct operating costs. Although they are derived in different fashions, it is believed that the hourly operating costs, as given, represent a comparable level of direct costs for the two types of vehicles. Where aircraft are compared with ships for the same mission, however, conclusions should be drawn with caution, particularly if the difference between the calculated costs is small.

Direct costs are determined on the basis of the number of hours of operation required of the vehicles for staging and recycling the necessary forces. This is believed to provide the most satisfactory criterion for measuring the commitment of resources to this operation. It is probably not the most convenient unit for billing costs between Federal agencies where vehicle-days, for example, might be more appropriate. Average daily costs, however, are not considered to provide a sufficiently precise standard for discriminating between vehicles and systems.

It perhaps bears mention that use of only the numbers of vehicles as a standard of cost implies that the operating costs of the vehicles are substantially equal. An operating system using the minimum number of vehicles is the minimum cost system only if all the vehicle unit costs are the same.

Average hourly operating costs in themselves hide a considerable possible variation in operating costs, of course. High speed operating hours of an aircraft cost more than long endurance hours, for example. The hourly cost determined from annual operating cost and annual hours underway exaggerates the expense of a tender which performs its major service at anchor. A compromise between precision and practicality must be made, however.

Aircraft Unit Costs. Direct operating costs for aircraft are generally considered to include the cost of fuel and oil, the flight crew, maintenance labor, and maintenance material including the consumption of spare parts. Inasmuch as we are interested in considering both Navy and Air Force airplanes, the summary cost in Table 20 includes all of these direct costs except for maintenance material, for which data were not available for most airplanes considered. It is not likely that addition of these figures would affect the relative costs of the airplanes, however.*

Fuel and oil costs have been drawn from references 48 and 53 . Maintenance manhours for USAF airplanes were obtained from reference 47 . In order to show maintenance labor costs for Navy aircraft consistent with the USAF figures, an equation based on the USAF factors was used to estimate them. Flight crew costs are based on the number of crewmen required for this mission. Annual pay for flight crews is assumed to average $7,750 for officers and $4,440 for enlisted crewmen. This annual pay is assumed to be allocated over the annual flying hours of the crew which are estimated to vary among the types of aircraft as follows:

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* Additional data, received too late to be used in this study, are given in Appendix C.

TABLE 20

AIRCRAFT DIRECT HOURLY OPERATING COSTS

Aircraft Model	Fuel & Oil (a,b)	Maintenance Man-Hours (c)	Maintenance Labor Cost @$2.25/Hour	Flight Crew No.	Flight Crew Cost	Total	Cruise Speed (Knots)	Cost Per Mile
B47	$227.49	51.2	$115.20	3	$77.40	$420.09	410	$1.025
B52D	356.90	115.6	260.10	6	133.00	750.00	460	1.630
C54(R5D)	41.47	18.0	40.50	3	39.90	121.87	156	.781
KC-97G	139.52	33.9	76.28	4	92.30	308.10	205	1.503
C119	51.05	26.3	59.18	5	64.30	174.53	160	1.091
RC121D (WV-2)	93.01	25.4	57.15	5 min. 26 max.	64.30 310.30	214.46 460.46	215	1.000 2.140
C124	113.68	33.4	75.15	5	64.30	253.13	-	-
C130A	92.57	31.0	69.75	4	55.40	217.72	290	.750
C133A	195.18	41.2	92.70	4	55.40	343.28	-	-
KC-135	223.06	(64.7)	145.58	4	92.30	460.94	455	1.013
P5M-2	39.17	(21.9)	49.28	11	168.00	256.45	150	1.710
P2V-6	51.18	(21.7)	48.82	7	117.00	217.00	170	1.278
S2F	17.54	(16.6)	37.35	4	75.00	129.89	130	1.000
SA-16/UF	25.01	22.6	50.85	4	85.30	161.16	135	1.196
H19, HRS, HO4S, S-55	6.42	14.0	31.50	3	83.15	121.07	-	-
H21	16.16	15.0	33.75	3	83.15	133.06	85	1.565
H43	9.57	13.0	29.25	3	83.15	121.97	-	-
HR2S-1, H37A, S-56	45.05	25.1	56.48	3	83.15	184.68	90	2.052
HSS-1, HUS, H34, S-58	14.98	21.5	48.38	3	83.15	146.51	85	1.724
ZPG-2 (d)	25.60*	(33.0)	74.25	24	272.70	372.55	40	9.300
Hydrofoil Boat	93.55	(30.0)	67.50	14	29.25	190.30	80	2.379

Note: Maintenance man-hours are based on USAF planning factors. Navy airplanes are estimated. For additional data on Navy aircraft, see also Table 37, Appendix C.

Source: (a) Reference 48 (c) Reference 47
(b) Reference 53 (d) Reference 34

* Includes Helium

Long range bomber	300 hours per flight crew per year
Transport	500
Patrol	350
Search	325
Helicopter	200
Airship	500

As a result, flight crew costs per hour are considered to be greater for helicopters, which are flown relatively few hours per year, than for transports which are flown a great deal.

Ship Unit Costs. Operating costs of U.S. Navy ships are based on the data in reference 49. These annual costs have been converted to an hourly basis by allocating them over annual hours underway as indicated in reference 50. Data for U.S. Coast Guard ships were obtained from USCG authorities.

It may be noted that for similar vehicles - such as WAVP and AVP - Coast Guard costs per hour are lower than Navy costs. In part, this may be due to the fact that the Navy figures are based on fiscal year 1959 dollars while those of the Coast Guard are based on fiscal 1958. The larger part of the discrepancy, however, is due to the higher ship utilization and lower manning requirements of the Coast Guard resulting from the difference in the peacetime missions of the two services. The effect of current operational usage on the apparent costs of the vehicles should be taken into consideration in evaluating their comparative costs for this mission.

Costs for hydrofoil boats, on which no current operational data are available, have been estimated using aircraft estimating methods and are shown in Table 20 with aircraft.

Comparative Cost of Retrieving Vehicles

The vehicles considered suitable for use as retrieving vehicles include surface ships, airships, and helicopters. Their comparative costs depend upon the number required to monitor a given area for a specified access time, and the operating costs incurred in reaching and maintaining station.

The number of vehicles required depends upon the speed capabilities of the vehicles. The greater their speed, the fewer will be required to cover the areas.

The total operational cost of the retrieving portion of the operation may be expresssed as:

TABLE 21

SHIP OPERATING & MAINTENANCE COSTS

		Total Annual O & M Cost ($ Thsd.)(a)	Annual Author. Personnel Cost ($ Thsd.)(a)	Annual Other O & M Cost ($ Thsd.)(a)	Annual Hours Underway (c)	Total Cost Per Hour Underway	Rated Speed (Knots)(b,d)	Average Speed (Knots) (c)	Total Cost Per Mile @ Average Speed
AD	Destroyer Tender	$3262	$2551	$ 711	1008	$3236	18	13.3	$243.3
AGC	Amphibious Force Flagship	2160	1587	573	1860	1161	16.4	10.9	106.5
AK	Cargo Ship (Inc. C1-M-AV1)	780	402	378	2592	301	{11.5 15.5	13.3	22.6
AKA	Attack Cargo Ship	1385	892	493	2196	631	16	11.9	53.0
AKL	Light Cargo Ship (Inc. FS)	179	116	63	2088	857	12	10.1	84.9
APA	Attack Transport	1808	1251	557	2040	886	16	11.5	77.0
APD	High Speed Transports	767	474	293	1848	415	23.6	11.7	35.5
ARG	Repair Ship (EC2 Liberty Hull)	1807	1436	371	888	2035	12.5	9.1	223.6
ASR	Submarine Rescue Vessel	499	275	224	1308	381	15	11.0	34.6
ATA	Auxiliary Ocean Tug	231	135	96	1584	146	13	10.1	14.5
ATF	Fleet Ocean Tug	417	222	195	2004	208	16	11.0	18.9
AV	Seaplane Tender	2925	2150	775	1932	1514	19	13.3	113.8
AVP	Small Seaplane Tender	971	524	447	2052	473	18	13.1	36.1
CVA(f)	Attack Aircraft Carrier (Forrestal)	11538	7962	3576	3276	3522	33	16.2	217.4
CVS(f)	Support Aircraft Carrier (ASW)	6650	4643	2007	2772	2399	33	14.1	170.1
DD	Destroyer	1255	757	498	2808	447	33	14.2	31.5
DDE	Destroyer Escort	1265	760	505	2616	484	33	14.3	33.8
DDR	Radar Picket	1288	778	510	2844	453	33	14.4	31.4
DE	Escort Vessel	908	531	377	1848	491	21	13.3	36.9
DER	Radar Picket Escort Vessel	935	551	384	3348	279	21	9.6	29.1
LSD	Landing Ship - Dock	1387	853	534	2184	635	{24 15	11.4	55.7
LST	Landing Ship - Tank	648	389	259	2028	320	11	9.3	34.4
MSO	Minesweeper Ocean (non-mag.)	336	189	147	1212	277	15	8.4	33.0
PC	Submarine Chaser	269	146	123	1020	264	16	12.0	22.0
PCER	Rescue Escort	410	245	165	1068	384	16	10.6	36.2
SS	Submarine	1285	395	890	2208	582	20	9.1	64.0
WAGL	Tender (U.S.C.G.) (e)	258	168	90	2000	129	12		
WAT	Ocean Tug (U.S.C.G.) (e)	377	236	141	2320	162	18		
WAVP	Tender (U.S.C.G.) (e)	648	425	223	3381	192	18		
WPG	Gunboat (U.S.C.G.) (e)	683	426	257	4051	169	18		

Notes:
(a) Reference 49
(b) Reference 22
(c) Reference 50
(d) Reference 23
(e) USCG data from Mr. M.B. Hopkins, Cost Analysis Branch USCG.
(f) Aircraft carrier costs include only ship operating costs, exclusive of embarked air group. Aircraft support costs are considered to be included in hourly aircraft operating costs.

$$TC = N\ (C_s + C_t)$$

where N = the number of retrieval stations required

C_s = cost per vehicle on station

C_t = cost per vehicle in transit to and from station .

The cost per vehicle on station may be expressed as

$$C_s = C \times t_s$$

where C = operating cost per hour

t_s = on time on station in hours.

The cost per vehicle en route to and from station from its base or previous station is

$$C_t = \frac{2DC}{rV}$$

where D = distance from base to station

V = rated speed of the vehicle

r = a factor which, multiplied by the rated speed of the vehicle, gives its normal cruising speed; r is considered to be the same for all vehicles.

The total operational cost is then given by

$$TC = CN\ (t_s + \frac{2D}{rV})$$

Vehicles Disposed Over an Area. Where the vehicles are disposed over a broad area, the number of vehicles is given by

$$N \geqq \frac{A}{kV^2 t_d^2}$$

where A = the area

t_d = "dash time", that is, the access time less allowance for delays, etc.; the time the recovery vehicle is actually travelling from its station to the capsule.

k = a constant, depending on whether the vehicle search areas are located in a square or hexagonal arrangement.

COMPARATIVE COST OF RETRIEVING VEHICLES DISPOSED OVER AREA

(CLOSE TO BASE)

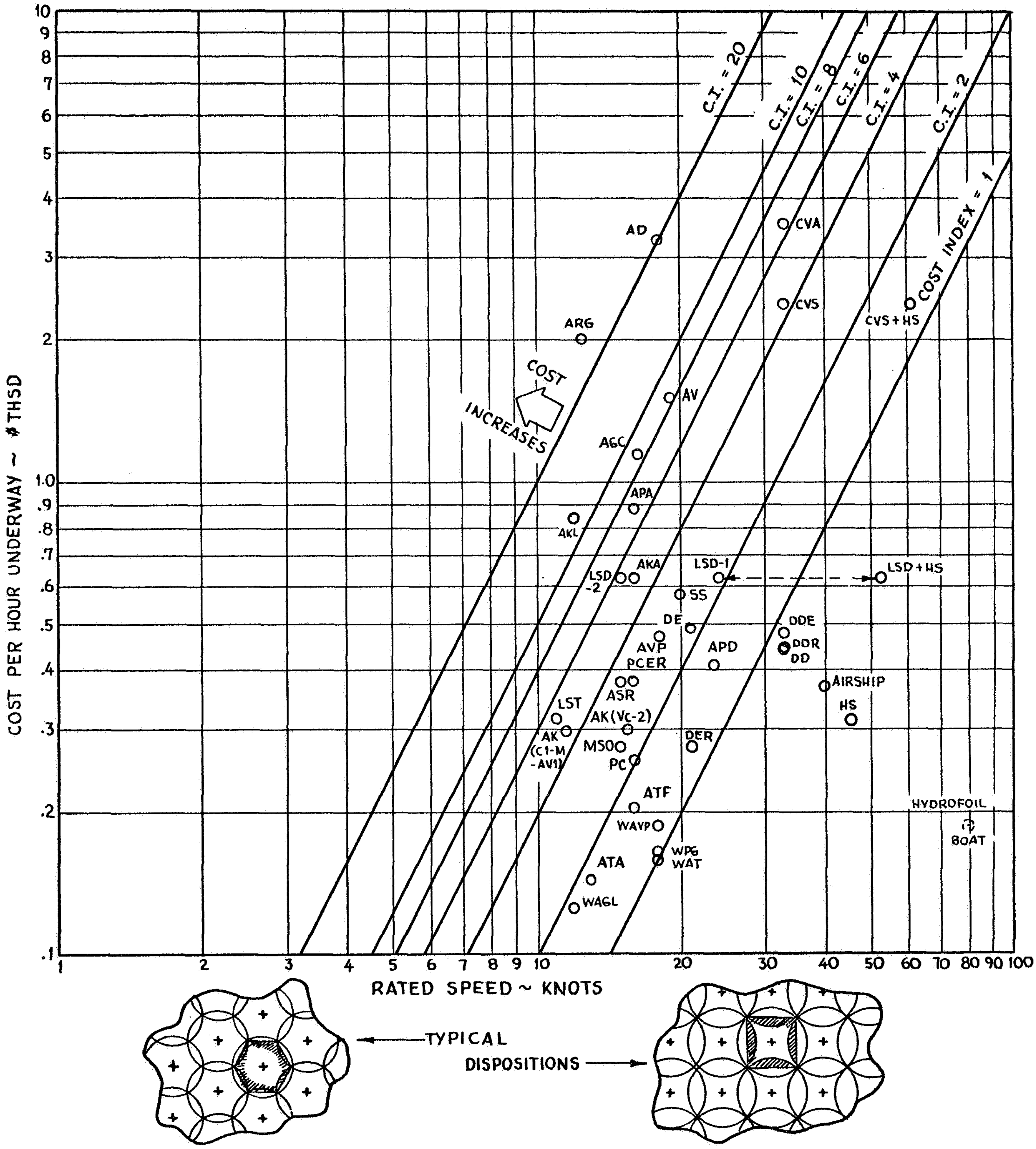


FIG. 31

N may be greater than the expression given for two reasons. Unless the vehicle coverage exactly coincides with the edges of the area, additional vehicles must be assigned to account for these edge effects. Also, an integral number of vehicles must of course be assigned. For consistency in the general cost comparison of vehicles, however, the minimum number will be assumed, i.e.

$$N = \frac{A}{kV^2 t_d^{\,2}}$$

The total cost using any type vehicle then is

$$TC = \frac{AC}{kV^2 t_d^{\,2}} \left(t_s + \frac{2D}{rV}\right)$$

The ratio of total cost, comparing two vehicles, is therefore

$$\frac{TC_1}{TC_2} = \frac{C_1}{C_2} \left(\frac{V_2}{V_1}\right)^2 \frac{t_s + \frac{2D}{rV_1}}{t_s + \frac{2D}{rV_2}}$$

where the subscripts denote the two vehicles.

Two limiting cases are of interest:

1. Where the distance from the point of departure of the vehicle to its station is negligibly small. This might be the case where the assigned area is close to the home port of a ship, or where a ship is already at sea nearby and is temporarily diverted to its retrieval station.

2. Where the distance from the point or departure is very great and the time on station, by comparison, is very small.

Examining first the case where the distance is small, D may be assumed to go to zero. In this event, the comparative costs are given by

$$\frac{TC_1}{TC_2} = \frac{C_1}{C_2} \left(\frac{V_2}{V_1}\right)^2$$

The comparative cost of possible recovery vehicles under these circumstances is illustrated in Figure 31. The vehicles are plotted according to their rated speed (assumed to be the dash speed) and their hourly operating cost.

The relative cost of a system using any one of these vehicle types may then be read by reference to the slanted cost index lines. For example, any system using vehicles found plotted along cost index 1 will cost the same as a system using vehicles found anywhere else along the cost index 1 line. A system using ships found along the cost index 2 line costs twice as much. The cost index lines provide a basis for comparison in any one of the Figures 31, 32, 34 and 35. They should not be construed

COMPARATIVE COST OF RETRIEVING VEHICLES DISPOSED OVER AREA

(DISTANT FROM BASE)

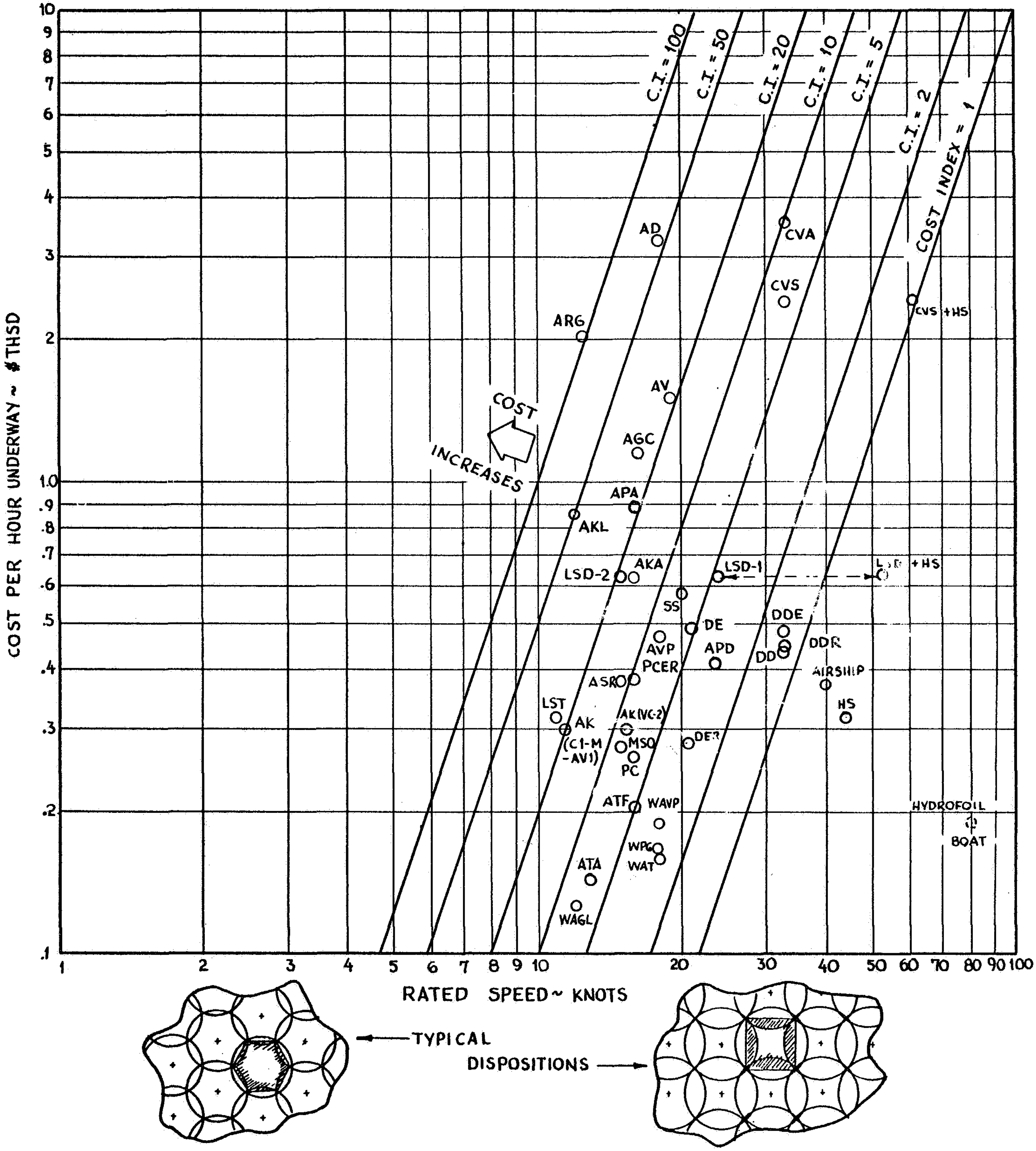


FIG. 32

to be consistent between figures, however.

Among the surface ships, the least expensive of the existing service types is seen to be the destroyer and similar vessels (DD, DDE, DDR). A number of auxiliary ships, however, approach the same general range of cost (between cost index 1 and cost index 2). These include the types: APD, ATF, ATA, DER, and the Coast Guard ships WAT, WPG, WAVP, and WAGL. It can be seen that relatively small changes in the values used for hourly cost could affect the relative standing of these types. The high current utilization of Coast Guard ships, for example, probably results in the WPG and WAT appearing less expensive in comparison to the DD than they might actually be when used for the same mission. Although the unit costs are not to be construed as highly precise values, the general conclusion here is that the destroyer types are to be preferred among surface vessels.

It is seen that vehicle velocity is critical in the cost comparison of these vehicles. At 40 knots, therefore, the airship can be seen to be less expensive than any of the surface vessels. The high speed of hydrofoil boats shows them to be a potentially attractive vehicle at the operating cost assumed.

Helicopters and helicopter-ship combinations are discussed below.

In the other limiting situation when the vehicles are to be stationed at a considerable distance from their home ports, the term t_s may be considered to approach zero. In the limit,

$$\frac{TC_1}{TC_2} = \left(\frac{C_1}{C_2}\right) \quad \left(\frac{V_2}{V_1}\right)^3$$

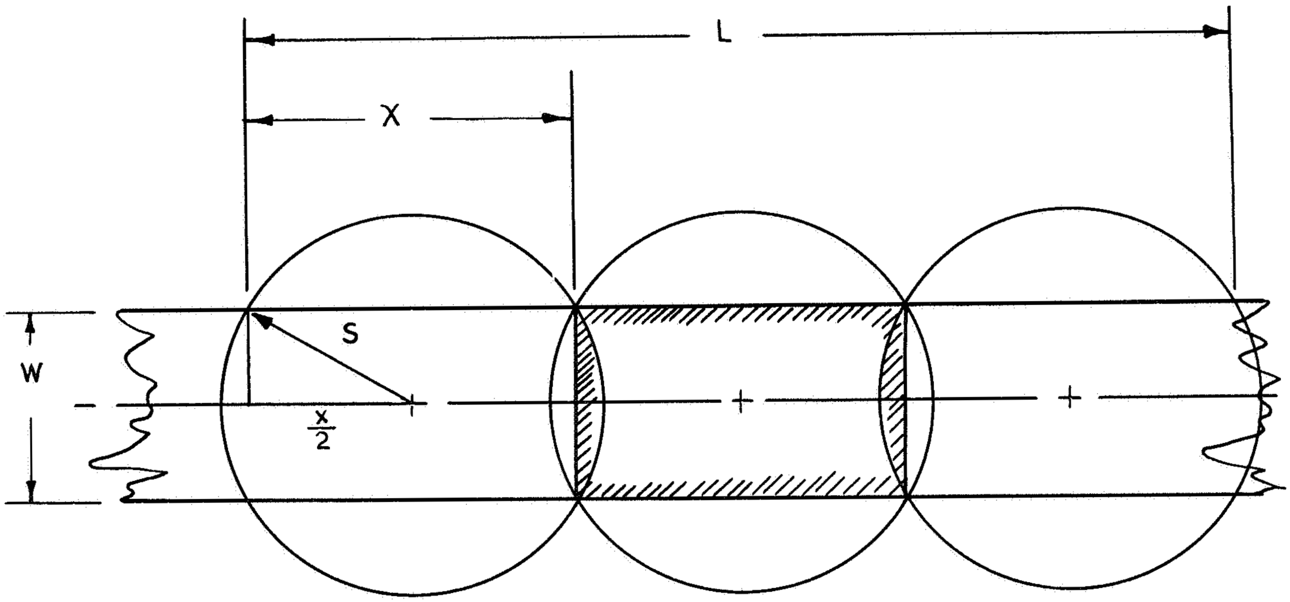
The comparative cost of the vehicles for this situation is shown in Figure 32. Vehicle velocity can be seen to be even more critical under these circumstances. The superiority of the destroyer types among surface vessels becomes more pronounced. Other high speed vessels such as the DE and higher speed LSD's are competitive economically with the small auxiliary types. Inasmuch as the hourly costs shown do not include a prorated cost of any tender or refueling vessel, those types which are self-sufficient for extended missions will have an advantage beyond that indicated in the plot.

Vehicles Disposed Along a Track. A more typical recovery area may consist of a relatively narrow band along the orbit track. Such bands can be covered by stationing the recovery vehicles in one column along the track. The area which these vehicles can reach within the required access times may include considerable sectors of their search circles on both sides of the high-probability band. The number of stations required to monitor the desired area under these circumstances, as illustrated in Figure 33 is given by

$$N = \frac{L}{\sqrt{4S^2 - W^2}}$$

GEOMETRY

NUMBER OF VEHICLES REQUIRED PER LENGTH OF TRACK



NUMBER OF VEHICLES (N) $= \frac{L}{X} = \frac{L}{\sqrt{4S^2 - W^2}}$

FIG. 33

where L = length of the area along the track

W = width of the area

S = radius covered by the recovery vessel in a given access time.

The radius S is given by

$$S = V \text{ (access time } -.25) = Vt_d$$

The number of stations required is therefore given by

$$N = \frac{L}{\sqrt{4V^2\ t_d^2 - W^2}}$$

and the total cost is

$$TC = \frac{CL}{\sqrt{4V^2\ t_d^2 - W^2}} \left(t_s + \frac{2D}{rV}\right)$$

Again, the relative cost of retrieve vehicles disposed along the track may be examined in two limiting conditions: where the distance from base may be considered negligible and D is considered zero, and where the distance from base is considered overruling and t_s approaches zero. The ratio of cost in these two extremes is given, respectively, by

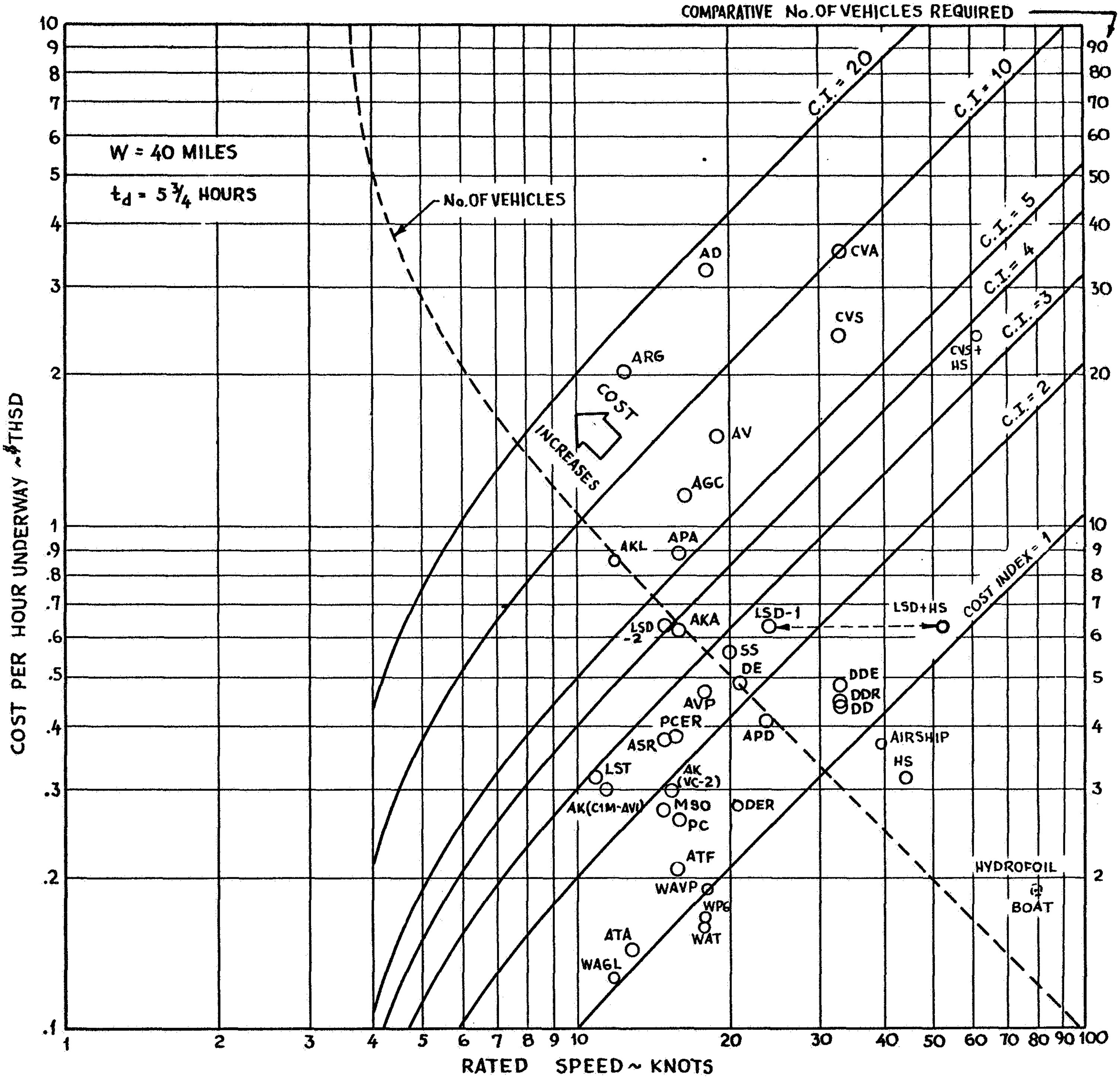
$$\frac{TC_1}{TC_2} = \left(\frac{C_1}{C_2}\right) \sqrt{\frac{V_2^2 - \left(\frac{W}{2t_d}\right)^2}{V_1^2 - \left(\frac{W}{2t_d}\right)^2}} \qquad (D = 0)$$

and

$$\frac{TC_1}{TC_2} = \left(\frac{C_1}{C_2}\right) \left(\frac{V_2}{V_1}\right) \sqrt{\frac{V_2^2 - \left(\frac{W}{2t_d}\right)^2}{V_1^2 - \left(\frac{W}{2t_d}\right)^2}} \qquad (t_s = 0)$$

The cost of alternative vehicles under these circumstances is shown in Figures 34 and 35 for a dash time of 5-3/4 hours and a track width of 40 miles. Superimposed on the plot is a diagonal reference line by which comparative number of vehicles required for a given track length may be read at the right-hand margin.

COMPARATIVE COST OF RETRIEVING VEHICLES
IN A SINGLE COLUMN ALONG TRACK
(CLOSE TO BASE)



TYPICAL DISPOSITION OF VEHICLES

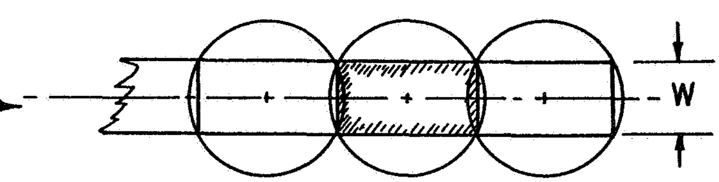
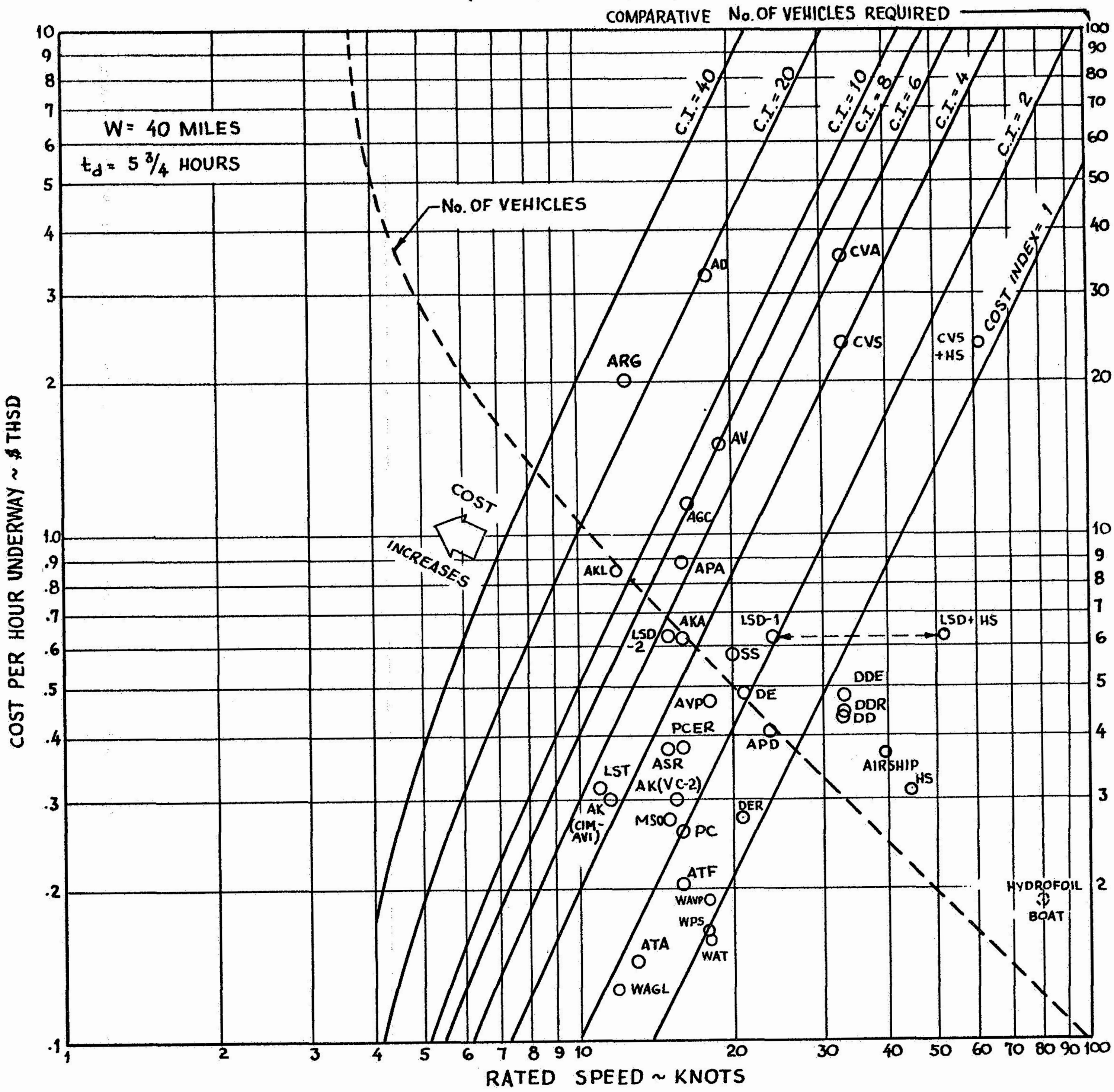


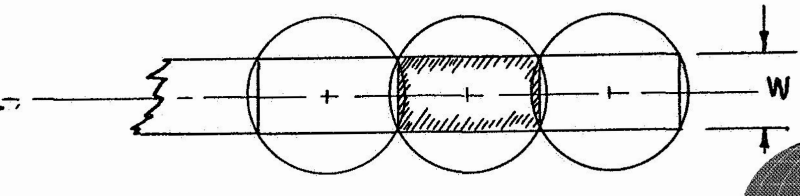
FIG. 34

COMPARATIVE COST OF RETRIEVING VEHICLES IN A SINGLE COLUMN ALONG TRACK

(DISTANT FROM BASE)



TYPICAL DISPOSITION OF VEHICLES



PRELIMINARY RECOVERY STUDY

FIG. 35

The comparative cost of vehicles arranged along a narrow band distant from their home bases, illustrated in Figure 35 , is seen to be virtually identical with that which occurs when the vehicles are disposed over an area close to home, Figure 31 . The destroyer types continue to show to advantage among the surface vessels. The economy of airships and potentially of hydrofoil boats is apparent.

When the vehicles are arranged in column close to base, the higher speed vessels lose some of their cost advantage, as indicated in Figure 34, although the same relative numbers are required. This type of recovery area would appear to provide the most suitable application of the low-speed auxiliaries.

Aerial Pick-up. Not appearing in the graphs are fixed-wing aircraft capable of aerial pick-up of the floating capsule. Operating at speeds of 150 knots or more and a cost of $175 to $225 per hour, it is apparent that it would have a decided cost advantage over any other retrieval system. This also applies to seaplanes.

Helicopters as Retrieving Vehicles. In comparing the cost of helicopters with other retrieving vehicles, it should be noted that they are peculiar in requiring no substantial station-keeping cost of themselves. Whereas surface ships and airships are "operating" and incurring operating costs while they are holding station, helicopters remain at their base and incur no more costs than it takes to warm them up. Unless the capsule actually impacts in their assigned area and they are dispatched to retrieve it, no additional expenses are incurred on station. A system using helicopters does incur a variable support expense: that of the ship or land base from which they operate. Unless a ship keeping station at sea is required, however, this support expense will be assumed to be no more than that normally allocated to direct operating cost. It is assumed that the support expense of a ship-based helicopter is that of a typical ship capable of use as a helicopter carrier, considered to be the LSD. It is assumed that the cost of transporting a helicopter to a land base will be that of the minimum suitable transport ship, considered to be the LST, or of a C-124 aircraft, whichever costs less.

The primary cost of a helicopter system then is that of the support vehicles required to place them on station. The direct operating cost of the one or two vehicles which may be dispatched for the actual pick-up is relatively insignificant compared to the overall system cost. On this basis, the helicopter may be examined within the cost framework shown in Figures 31 , 32 , 34 and 35 at the operating cost level of the support ship and at an "effective" rated speed which depends upon its own speed and range, and the speed of the ship on which it may be based. Although access to the capsule may be gained in flight with the larger helicopters, it will be assumed for the purpose of cost comparison that return to base is necessary for complete retrieval of the capsule.

Ship-based Helicopters. The number of retrieval vehicles, we have seen, depends upon the radius which can be reached by the vehicle within a given access time. Basing a helicopter aboard ship reduces the number of stations required by giving the ship longer legs. Within the range capabilities of the helicopter, the effective radius for a given access time may be determined as a function of the speed

capabilities of the aircraft and ship and the access time. The helicopter may be assumed to be in flight for the previously described "dash time" reduced by an additional six minutes for helicopter launch, capsule pick-up, and helicopter recovery. Neglecting reduction in speed resulting from the capsule load, the distance covered by the helicopter is

$$V_h \ (t_d - 0.1)$$

where V_h is helicopter speed.

During the same period the ship travels a distance equal to

$$V_s t_d$$

where V_s is ship speed.

The effective radius is therefore

$$S = \frac{V_h \ (t_d - 0.1) + V_s t_d}{2}$$

The "effective" rated speed is therefore

$$V_{eff} = \frac{V_h(1 - \frac{0.1}{t_d}) + V_s}{2}$$

The term $(\frac{0.1}{t_d})$ may be neglected without prejudicing the precision of this comparison. The effective speed, then, is the average speed of the helicopter and the ship on which it is based.

For a 90-knot helicopter based on a 15-knot ship, the effective speed is therefore 52.5 knots. This combination is shown for reference in Figures 31 , 32 , 34 , and 35 at the operating cost of an LSD. For a 90-knot helicopter based on a 33-knot CVS aircraft carrier, the effective speed is 61.5 knots, as also indicated in the figures. Although the carrier is in fact capable of supporting many aircraft, its entire operating cost is allocated to the single helicopter which retrieves the capsule if the carrier serves only as a retrieving vehicle support vessel. In areas where the permissible access time is so great that the helicopter, because of its range limitations, cannot be used during the full time that the ship is closing on the capsule, the effective radius of the combination is curtailed and the cost advantage over the ship operating without a helicopter is reduced. For this reason, the effective speed of the LSD-HS combination may extend from that of the LSD alone to the average speed of an LSD and helicopter, as indicated in Figures 31 , 32 , 34 , and 35 . The choice between the LSD-HS combination and the destroyer types (DD, DDE, DDR) will therefore depend upon the degree to which the helicopter may be utilized under the particular circumstances of area size and shape and allowable access time.

<u>Land-based Helicopters</u>. When the helicopters operate from land bases, they lack the advantage of a base which closes on the capsule as they retrieve it. In this event, the effective speed of the helicopters may be considered simply one-half their cruise speed. On the other hand, they are not penalized by the cost of a support vehicle which may be at sea 24 hours a day in order to maintain a retrieval station for, at most, 4 to 8 hours daily. Considered at the cost of an LST as shown in Figures 31, 32, 34, and 35, the helicopter compares very favorably with the most economical surface ships. Inasmuch as this is a high estimate of its cost on station, the land-based helicopter is in fact much more economical than the figures suggest.

Comparative Cost of Detection Vehicles

The operating cost of the detection system depends upon the number of detection stations required and the cost of maintaining the detection vehicles on station. These in turn depend upon the

1. Hourly operating cost of the vehicles
2. Time-radius curve of the vehicles
3. Endurance on station required
4. Distance of the station from the vehicle base
5. Altitude at which the vehicle operates.

<u>Number of Stations Required for Continuous Coverage</u>. The number of detection stations required depends upon the detection range. The primary means of detection include visual search, radar search, and radar or radio homing on a beacon. To provide an appreciable search radius for surface targets, the detection vehicles must operate at altitude; airborne vehicles only are therefore appropriate for this purpose. Line of sight range is taken as the measure of search radius, taking into consideration atmospheric refraction as indicated in Figure 7.

Feasible search radii may be much greater than the width of the areas to be monitored, in which case the detection vehicles will be arranged in a column along the orbit track. If all portions of the high probability impact areas are to be kept under continuous surveillance, the number of detection stations per unit length of track is given by

$$N = \frac{L}{\sqrt{4S^2 - W^2}}$$

as illustrated in Figure 33 where N = number of detection stations, S = detection radius, and L and W are as defined above. Since line of sight detection radius is a function of altitude, the number of detection stations required is

$$N = \frac{L}{\sqrt{4\,kh - W^2}}$$

where h = altitude
k = a constant, defined by Figure 7.

Cost Per Hour On Station. The cost of using a particular vehicle to man a given detection station depends upon the time it spends in transit to and from its base as well as the time required on station. Vehicle operating cost may therefore be expressed to advantage in terms of cost per hour on station. This is given by

$$C_s = C \times \frac{\text{Time on station + transit time}}{\text{Time on Station}}$$

C_s = cost per hour on station

C = operating cost per hour

When the airplane is operating at the limit of endurance, this may be expressed as

$$C_s = \frac{\text{Endurance}}{\text{Time on Station}}$$

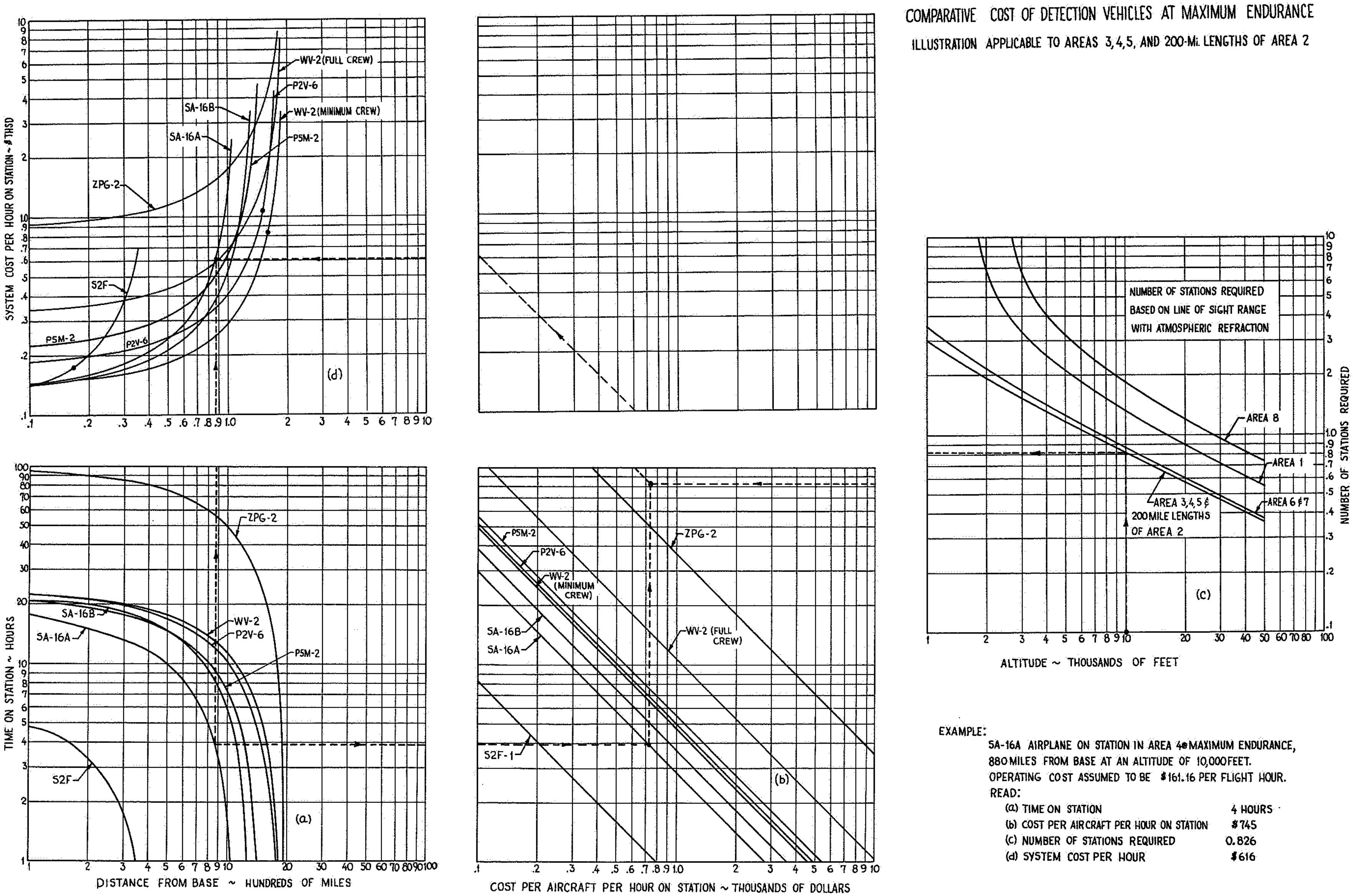
Vehicle Cost Comparison at Limit of Endurance. A comparison of the detection system cost using the several aircraft of primary interest at maximum endurance is developed in Figure 36 . The time-radius curves for the airplanes are given in section (a) showing the endurance on station at any distance from base. The vehicle cost per hour on station for this combination of radius and time on station is shown in section (b). The number of detection stations is given in section (c) as a function of operating altitude for several of the specific areas discussed in the following section. The detection system cost for a given area may be plotted as in section (d). Section (d) gives the vehicle operating cost for an area 40 miles wide by 200 miles long. Costs for areas of different size may be established following the method described in the example.

It can be seen that, except for short radii where there is little to choose between several models, the WV-2 operating with minimum crew gives the lowest detection system cost among land-based aircraft. This is primarily due to the fact that it is considered to operate at 15,000 feet; the remaining fixed-wing aircraft operate at 10,000. If the WV-2 is operated with full complement aboard, including relief crew and radar observers, it becomes more expensive than the SA-16 and P2V, even with its altitude advantage. The airship, operating at 1500 feet, would be by far the most expensive if used only as a detection vehicle. It should be kept in mind, however, that if the airship is included in the system as a retrieving vehicle, its contribution to the detection system is without additional cost.

Vehicle Cost Comparison for Fixed Time on Station. It is probably unrealistic to compare vehicles on the basis of their maximum endurance, particularly at short ranges. Airborne detection aircraft are likely to be on station from a few minutes before the scheduled launch of the capsule, through any required hold period, and, in the event of capsule impact in their assigned area, for a period approximately equal to the access time. It is anticipated that any shot which is delayed beyond a few hours is likely to be postponed until the following day. While surface ships may be required to remain in the vicinity of their stations until the following day, the aircraft (perhaps excluding airships) would return to base. On-station capability of 4 to 8 hour should be sufficient under these circumstances, and a

COMPARATIVE COST OF DETECTION VEHICLES AT MAXIMUM ENDURANCE

ILLUSTRATION APPLICABLE TO AREAS 3, 4, 5, AND 200-Mi. LENGTHS OF AREA 2



EXAMPLE:

SA-16A AIRPLANE ON STATION IN AREA 4 @ MAXIMUM ENDURANCE, 880 MILES FROM BASE AT AN ALTITUDE OF 10,000 FEET.
OPERATING COST ASSUMED TO BE $161.16 PER FLIGHT HOUR.
READ:

(a) TIME ON STATION	4 HOURS
(b) COST PER AIRCRAFT PER HOUR ON STATION	$745
(c) NUMBER OF STATIONS REQUIRED	0.826
(d) SYSTEM COST PER HOUR	$616

FIG. 36

COMPARATIVE COST OF DETECTION VEHICLES FOR 4 HOURS ON STATION

(PER 200 MILES OF 40-MILE WIDE TRACK)

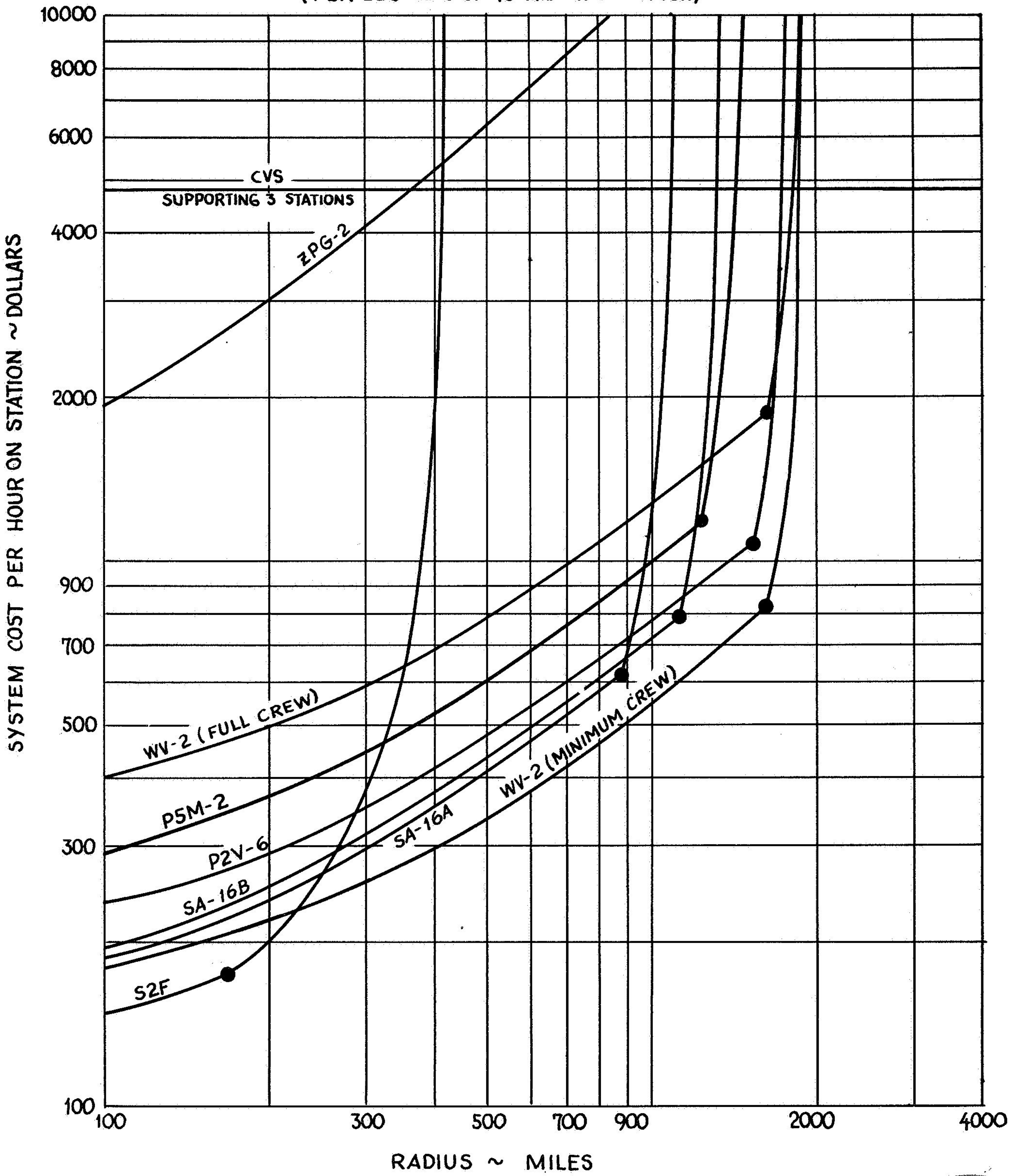


FIG. 37

COMPARATIVE COST OF DETECTION VEHICLES
FOR 8 HOURS ON STATION

(PER 200 MILES OF 40-MILE WIDE TRACK)

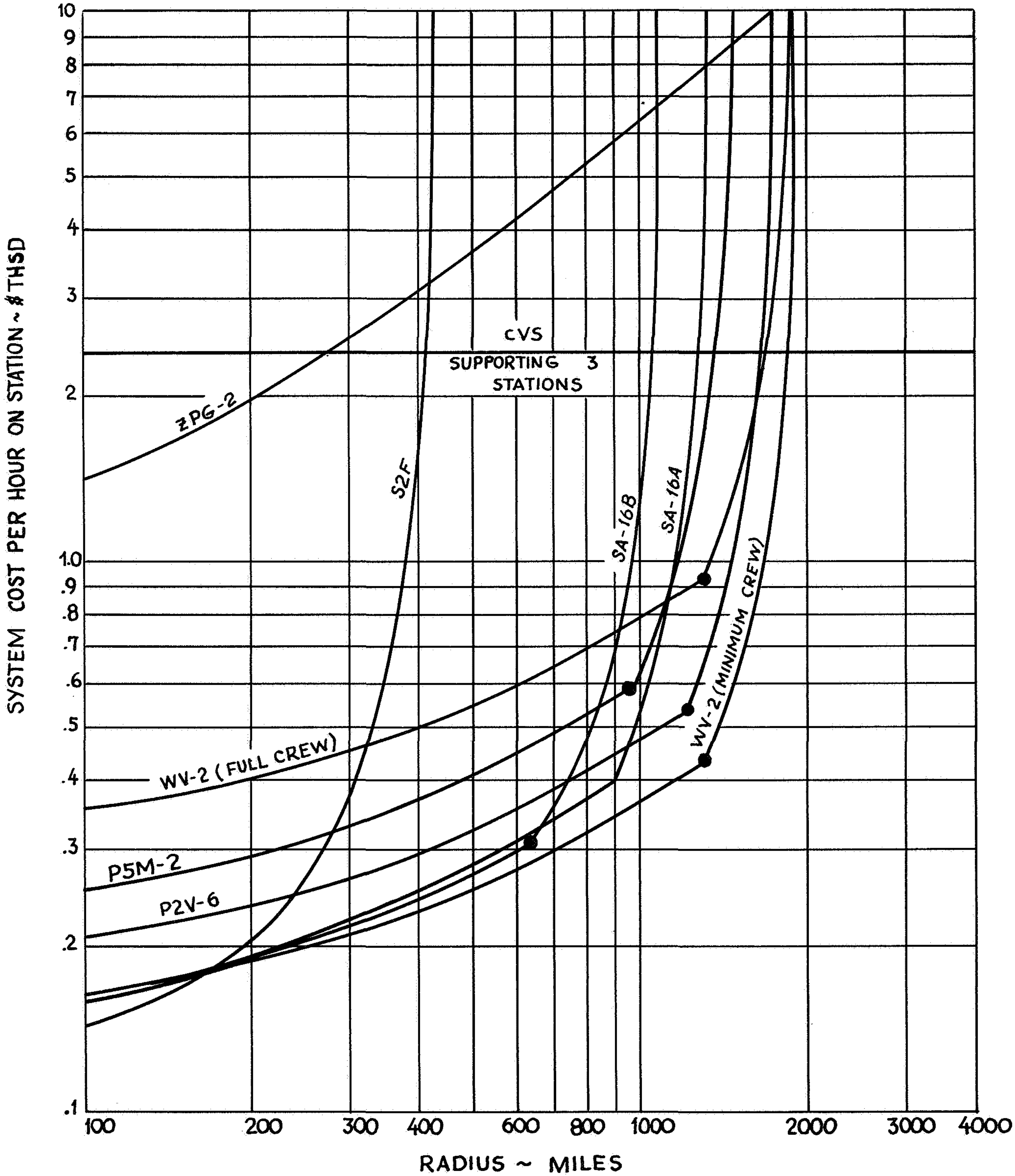


FIG. 38

cost comparison based upon maximum endurance militates unduly in favor of long endurance aircraft.

To provide a more realistic comparison for short ranges, the detection system operating cost is determined for the same aircraft for 4 and 8 hours on station, as shown in Figures 37 and 38. Up to a radius of about 200 miles, the land-based S2F is seen to provide the least expensive system. Beyond that radius, the WV-2 with minimum crew continues to be the least expensive, followed by the SA-16 and P2V. The cost per aircraft per hour on station increases with radius inasmuch as the aircraft spends a greater portion of its mission time in transit to and from station. The cost for any of the airplanes shown increases at about the same rate as radius is increased up to the point where the limit of endurance of the airplane is reached. System costs increase sharply at this point, the radius at which relief on station is required to maintain the minimum station time specified.

Ship-based Aircraft as Detection Vehicles. If detection aircraft are ship-based, they may be permitted to remain on deck during any delays in the firing. Even where continuous surveillance of the high-probability impact areas is required, it should not be necessary to launch aircraft which are capable of reaching their assigned stations before the capsule arrives overhead. Also, a delay between the possible impact of the capsule in an area and the arrival on the scene of the detection aircraft may be permissible. Where deck-holds are feasible, the cost of the detection system will be less than if the detection aircraft were required to be airborne during firing holds. The system cost under these circumstances is determined in a manner similar to that used for evaluating the cost of helicopters as retrieving vehicles. The operational cost of the system is that of the support vehicle allocated to the stations for which its aircraft are responsible during the alert period. If, on the other hand, the aircraft are required to be airborne during this period, their operating cost must be added to that of the support vehicle to determine the total cost of maintaining the station.

If the capsule impact may take place in a broad area around the carrier, the ship will be capable of maintaining a number of stations: equal, at most, to the number of detection aircraft it is capable of accommodating. However, if the probable impact area is a narrow band, the carrier is handicapped since only one or two of its aircraft may be able to reach useful detection stations. If a carrier is used, presumably it will also carry helicopters so that it can also man one retrieving station. At most, however, it will be capable of supporting two or three stations altogether, and the entire cost of the carrier must be borne by these few airplanes.

Further, it must be assumed that the aircraft carrier, like other ships used, will remain in the area of its assigned station from one day to the next, in the event of delays in the firing. The entire daily cost of the carrier, therefore, must be allocated to those relatively few hours when it is on alert status. The effective operating cost of the ship must be increased in inverse proportion to its hours on alert. That is, if it must stand by for four hours per day for firing holds, its operating cost is effectively multiplied by $24/4 = 6$. If eight-hour holds are anticipated, its effective cost is three times its hourly operating cost. The shorter the daily holds anticipated in the event of firing delays, therefore, the less economical the carrier appears as a support vessel.

GEOMETRY OF VEHICLE SPACING

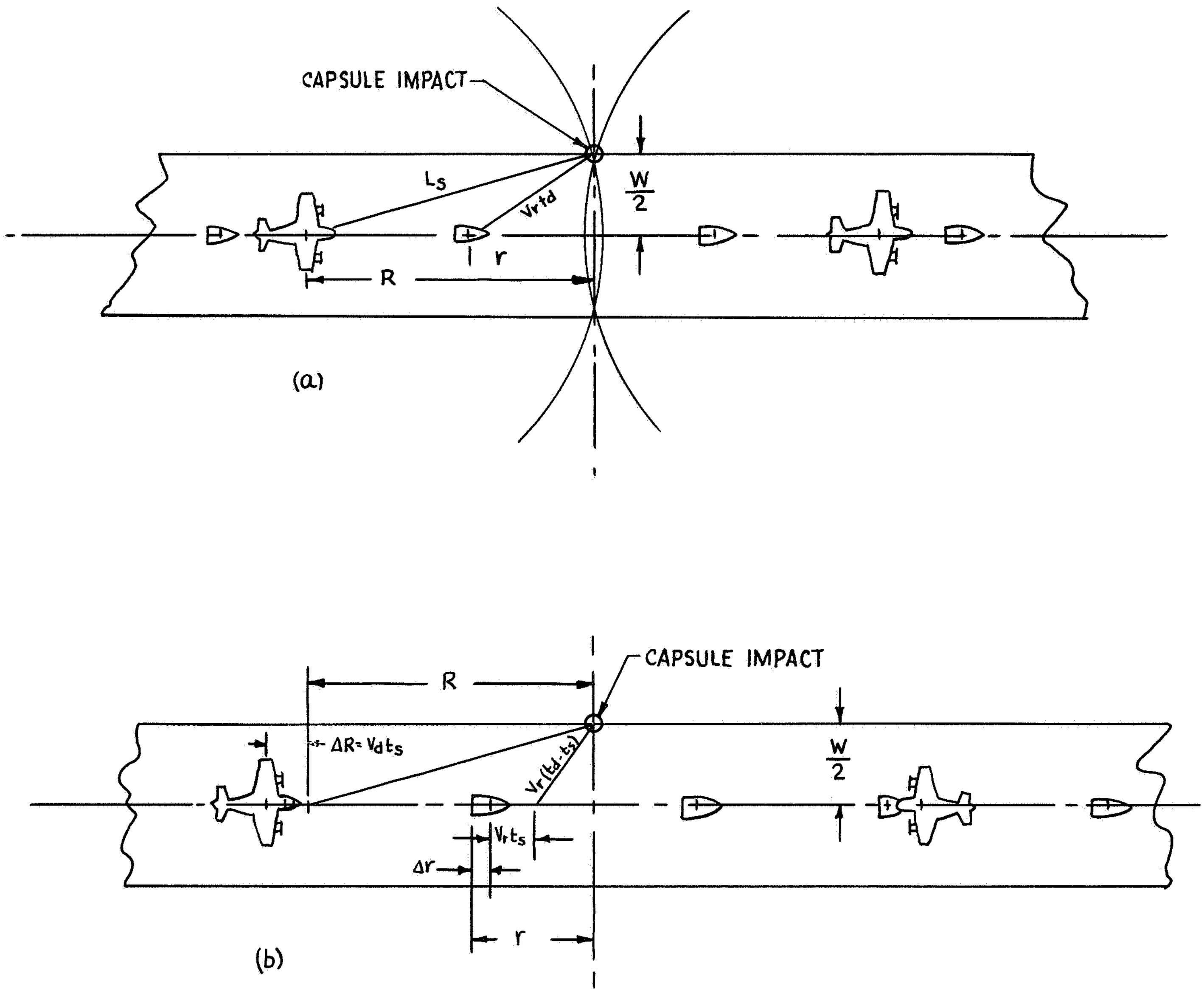


FIG. 39

To compare the absolute cost of the carrier for this mission to land-based aircraft, its hourly operating cost per station is shown in Figures 37 and 38 together with the on-station cost of the land-based airplanes. It is apparent that the carrier is economically preferable only at ranges 1800 miles or more from possible land bases for the aircraft indicated.

Aircraft on Ground Standby. The economies of deck-holds apply as well to land-based aircraft which are able to satisfy their detection mission requirements by taking off after the actual firing. Since there is no support ship, the only costs incurred are those required for warm-up and standby: virtually nothing. Detection stations which can be manned by aircraft on the ground are therefore the least expensive to maintain. The longer the delays anticipated, the more desirable it is to have airplanes on ground standby.

Effect on System Cost of Increased Spacing of Detection Vehicles

The cost of the detection system derived in the previous section is predicated on complete surveillance of the high-probability areas at all times. The detection vehicles are located close enough to each other along the orbit track so that any high-probability impact point is constantly within the detection range of at least one of them. Greater spacing of the detection vehicles may reduce the system cost. Reduction in the cost of the detection system, however, is bought at the price of an increase in the cost of the retrieval system. The minimum cost system occurs where the savings achieved by using fewer detection vehicles are just offset by the increase in cost due to the need for additional retrieval vehicles.

Increased spacing of the detection vehicles implies that they are permitted time to reach the scene after impact of the capsule. Assuming that the detection vehicle closest to the impact point has general knowledge of its location, that is, he knows whether to proceed in or out along the orbit track on the basis of predicted impact point intelligence, his effective range is increased by the distance he travels along the track before coming within detection range of the capsule.

On the other hand, the effective radius of the retrieving vehicles is reduced if travel time is permitted the detection vehicles inasmuch as access time is to remain the same. It must be assumed that the retrieving vehicle is not steering directly toward the capsule until vectored to it by the detection vehicle. (If it were capable of doing so, there would be no need for a separate detection system.) The operational situation may be described as in Figure 39.

Figure 39 (a) shows the situation when there is complete surveillance by the detection vehicles. The spacing between detection vehicles is 2R and between recovery vehicles is 2r. If the impact is considered to occur midway between adjacent vehicles, that is, at the point most remote from them, vehicle spacing is determined by the track width, the speed of the retrieving vehicle, and the search range of the detection vehicle:

$$N_d = \frac{L}{2\sqrt{L_s^2 - \frac{W^2}{4}}}$$

$$N_r = \frac{L}{2\sqrt{V_r^2 t_d^2 - \frac{W^2}{4}}}$$

where N_d = number of detection vehicles per length of track L

N_r = number of retrieving vehicles per length of track L

L_s = search range of the detection vehicle.

W = track width

V_r = speed of the retrieving vehicle

t_d = dash time, as defined above.

Figure 39 (b) shows the situation when the detection vehicle is permitted time to travel to within range of the capsule. It is assumed that when the capsule impacts, both vehicles proceed along the orbit track in the direction of the impact. The spacing of the detection vehicles is then increased by an amount ($2 \times \Delta R$) where ΔR is the distance the detection vehicle moves along the track during the travel time (t_t). The number of detection vehicles required is therefore reduced to

$$N_d = \frac{L}{2\ (R + \Delta R)} = \frac{L/2}{V_d t_t + \sqrt{L_s^2 - \frac{W^2}{4}}}$$

where V_d = speed of the detection vehicle.

During the period (t_t), the retrieving vehicle has been proceeding along the orbit track. The retrieving vehicle is assumed to continue in this direction during a period (t_f) until the detection vehicle conducts a local search and is able to vector the retrieve vehicle to the capsule. The spacing of the retrieving vehicles has been reduced by an amount ($2 \times \Delta r$). The distance ($r - \Delta r$) is given by

$$(r - \Delta r) = V_r\ (t_t + t_f) + \sqrt{V_r^2\ (t_d - t_t - t_f)^2 - \frac{W^2}{4}}$$

as shown in Figure 39 (b). The number of retrieving vehicles required is therefore

$$N_r = \frac{L/2}{(r - \Delta r)} = \frac{L/2}{V_r\ (t_t + t_f) + \sqrt{V_r^2\ (t_d - t_t - t_f)^2 - \frac{W^2}{4}}}$$

It is possible, of course, that the recovery vehicle, such as a surface ship, will see the capsule during the final descent with its own detection equipment and will have a better interim heading to steer. Less ground will be lost under these cir-

cumstances than if the retrieving vehicle steers along the orbit track. This analysis will indicate closer retrieving vehicle spacing and a greater number of retrieving vehicles per length of track than if greater retrieving vehicle intelligence is granted.

For a given set of conditions, then, the numbers of detection vehicles and retrieval vehicles may be determined over a range of permissible travel times. This is illustrated in Figure 40 for two sets of conditions, representing the extremes of detection airplane capabilities:

Situation A	Situation B
V_d = 200 knots	V_d = 150 knots
L_s = 150 miles	L_s = 35 miles
t_f = 0 hours	t_f = 1.5 hours

W = 40 miles

V_r = 25 knots

t_d = 5.75 hours

To determine the optimum travel time which minimizes the cost of the combined detection and retrieval systems, it is necessary to take into consideration the relative costs of the detection and retrieving vehicles. If the cost of detection vehicles is high compared to retrieving vehicles, for example, the optimum ratio of detection vehicles to retrieving vehicles will be comparatively low. The optimum travel time may be expected to be greater under these circumstances than if the cost of detection vehicles were low.

If the operating cost of the detection and retrieving vehicles are the same, the minimum cost system will also be the system in which the number of vehicles is a minimum.

The total cost of the combined detection and retrieval system is

$$TC = TC_d + TC_r$$

$$TC = C_d N_d + C_r N_r$$

where C_d = operating cost on station of the detection vehicle

C_r = operating cost on station of the retrieving vehicle.

TC_d = total cost of the detection system

TC_r = total cost of the retrieval system.

COMPARATIVE NUMBERS OF DETECTION & RETRIEVING VEHICLES FOR REDUCED SURVEILLANCE COVERAGE
TYPICAL CASE

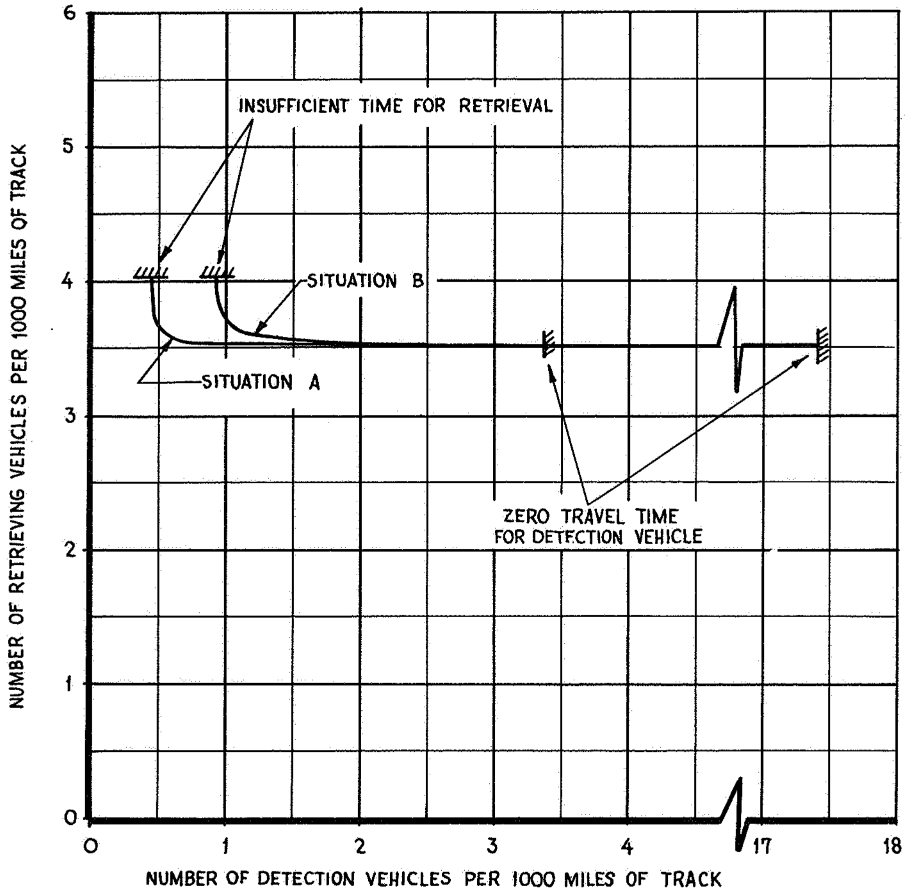


FIG. 40

ALLOWABLE TRAVEL TIME FOR MINIMUM COST
TYPICAL CASE

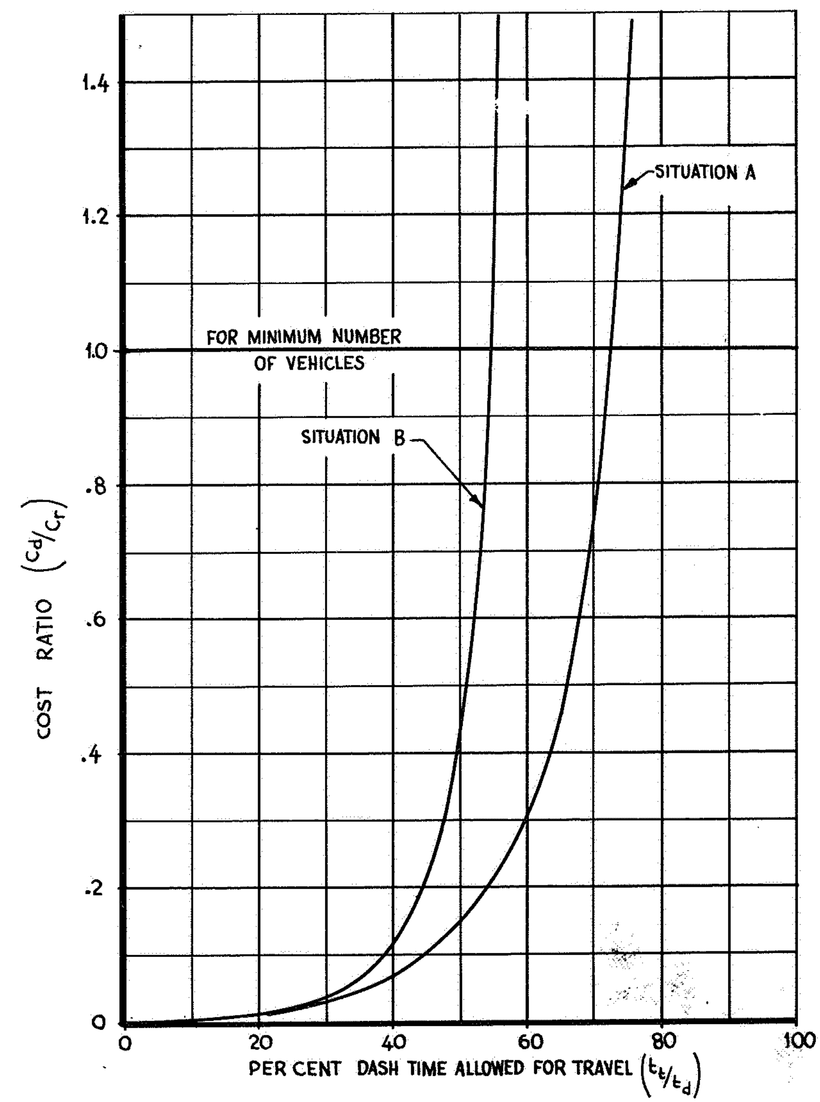


FIG. 41

confidential

Substituting the appropriate values for N_d and N_r gives the total cost as

$$TC = \frac{C_d L}{2} \frac{1}{V_d t_t + \sqrt{L_s^2 - (\frac{W}{2})^2}} + \frac{C_r L}{2} \frac{1}{V_r (t_t + t_f) + \sqrt{V_r^2 (t_d - t_t - t_f)^2 - (\frac{W}{2})^2}}$$

The conditions for minimum cost are determined by differentiating the total cost with respect to the travel time (t_t) and setting the result equal to zero. The ratio of operating costs of the detection and retrieving vehicles as a function of travel time is found to be

$$\frac{C_d}{C_r} = \frac{V_d}{V_r} \left[\frac{C}{B} - 1\right] \left[\frac{x + F}{x + B}\right]^2$$

where the simplifications

$$A = \frac{W}{2V_r t_d}$$

$$B = \sqrt{C^2 - A^2} = \sqrt{\left(\frac{t_d - t_t - t_f}{2}\right)^2 - \left(\frac{W}{2V_r t_d}\right)^2}$$

$$C = \frac{t_d - t_t - t_f}{t_d}$$

$$E = \frac{W}{2V_d t_d}$$

$$F = \sqrt{G^2 - E^2} = \sqrt{\left(\frac{L_s}{V_d t_d}\right)^2 - \left(\frac{W}{2V_d t_d}\right)^2}$$

$$G = \frac{L_s}{V_d t_d}$$

$$x = \frac{t_t}{t_d}$$

have been made. This relationship is shown in Figure 41 for the typical conditions previously described. For any ratio of vehicle operating costs, the optimum travel time for a minimum cost system is specified as a percentage of the dash time. It may be seen that in the case illustrated, the allowable travel time exceeds 40% of the dash time whenever the cost of the detection vehicles is more than 7 to 12% of that of the retrieving vehicles.

The travel time which permits the minimum number of vehicles is determined by assuming the ratio of costs is 1.0 and is seen to range between 54.5 and 72.5% for the extremes considered.

The total system cost may be shown as a multiple of the cost of detection system with complete surveillance:

TOTAL SYSTEM COST AS A FUNCTION OF DETECTION SYSTEM COVERAGE
TYPICAL CASE
(CONSTANT ACCESS TIME)

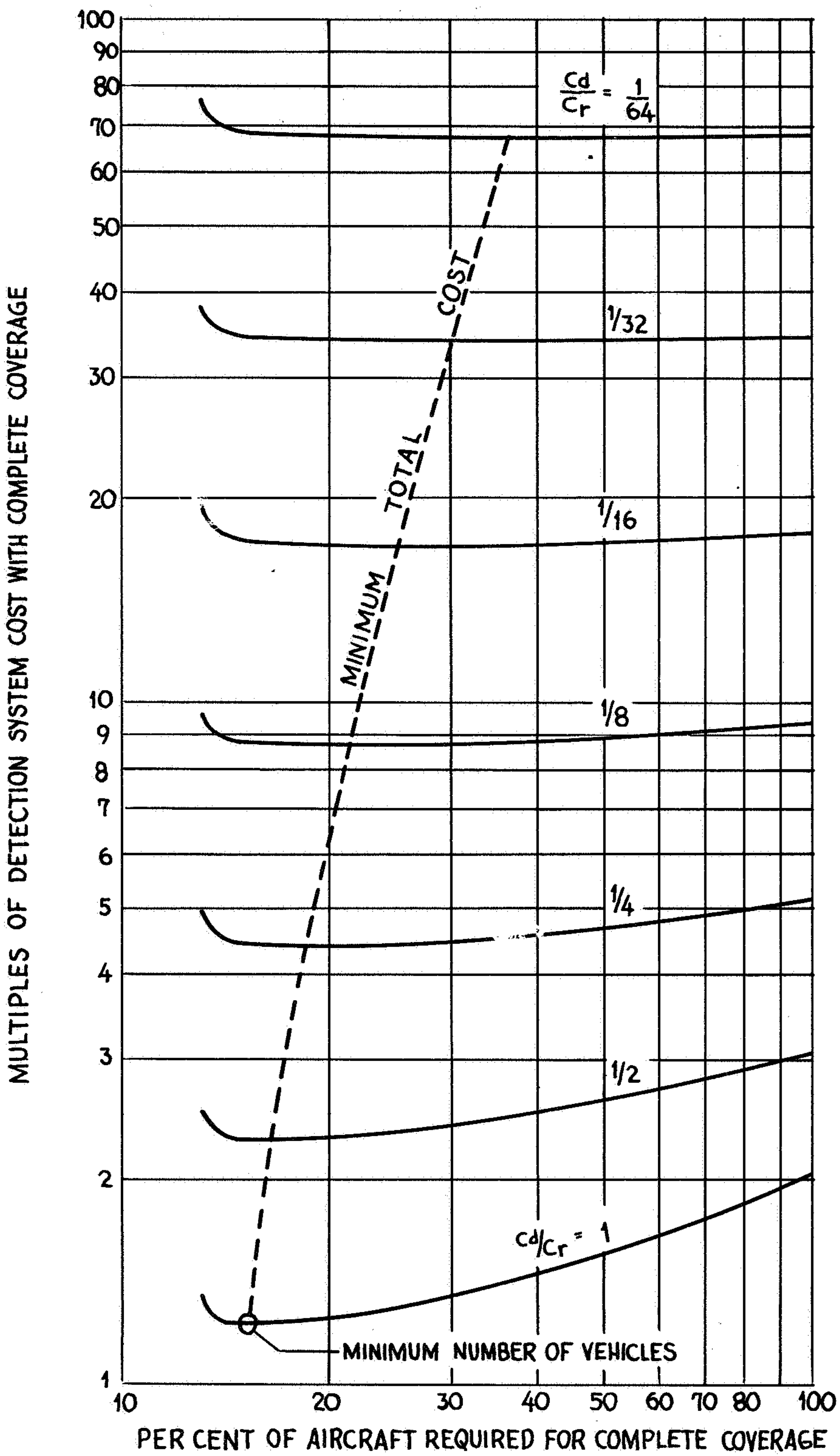


FIG. 42

$$\frac{TC}{TC_{d_o}} = \frac{TC_d}{TC_{d_o}} + \frac{TC_r}{TC_{d_o}}$$

where the subscript "o" denotes the complete surveillance system. Total system cost is presented in this manner in Figure 42 to describe Situation A for a range of ratios of the operating costs of the detection and recovery vehicles. The minimum total cost for a range of vehicle cost ratios is shown as a diagonal broken line.

It may be seen that minimum cost is obtained when the number of detection vehicles is reduced to 15 to 37% of that required for complete surveillance for the range of cost ratios considered. The greater the cost of the retrieving vehicles, the more detection vehicles required for minimum system cost. The cost of the total system, however, is relatively insensitive to the number of detection vehicles, particularly when they are inexpensive compared to retrieving vehicles. The minimum number of vehicles (read where the cost ratio equals 1) is obtained where the number of detection vehicles is reduced to about 15% of that required for complete surveillance. This minimum is approximately 60% of the total number of vehicles required for a system which requires complete surveillance.

Summary. The major operational expenditures incurred in the recovery of the Project Mercury capsule will be due to the staging and possible recycling of the detection and retrieving forces to and from their stations preparatory and subsequent to the capsule firing. The measure of these expenditures is taken as the operational cost of the vehicles used based on the number of operating hours they are required, including fuel, oil, and other consumables, an apportioned share of the maintenance required, and the pay and allowances of the personnel directly involved. Ships and aircraft which appear suitable for the detection and retrieving missions are evaluated on this basis.

Among the feasible retrieving vehicles, land-based helicopters appear to be the most economical within their range limitations, primarily because they incur virtually no cost during delays and holds. Beyond the range of the land-based helicopter, the airship offers the most economical alternative up to the limit of its operational suitability. Among surface ships, the destroyer-types appear the most economical for general application. Small auxiliary vessels may be suitable for monitoring narrow tracks close to their home ports. The ship-based helicopter compares favorably with the destroyer provided that the permissible access times are such that the endurance capabilities of the helicopter are not greatly exceeded. Very high speed vehicles such as the hydrofoil boat and the airplane capable of water pick-up of the capsule would be very economical operationally.

The comparative costs of aircraft considered suitable for detection vehicles depend upon the range at which they must operate. For ranges out to about 1800 miles, the WV-2 operating with minimum crew appears most economical of the aircraft considered, although land-based S2F's are cheaper within their range capabilities for reasonable firing delays. If the WV-2 is operated with full crew, however, it is more expensive than the SA-16 and P2V at intermediate ranges. The

use of carrier-based aircraft appears justified only for areas more than 1800 miles from land bases, and would be most appropriate where the area to be monitored is not limited to a narrow band along the orbit track.

Substantial savings in total system cost may be achieved if complete, continuous surveillance of the high-probability impact areas by the detection vehicles is not required. If the detection vehicles are required only to locate the capsule in time to direct the retrieving vehicle within a given access time, they may be reduced in numbers considerably without causing an appreciable increase in the number of retrieving vehicles required. Further savings may be achieved by permitting them to stand by on the ground during firing holds rather than maintaining airborne stations.

OPERATIONAL EFFECTIVENESS CONSIDERATIONS

The foregoing sections discuss the elements of an overall recovery operation in some detail, cast in a fairly general frame of reference so as to be broadly applicable to any recovery of a manned orbital capsule from the sea. Each and every element serves as a necessary source of information for deriving or evaluating a system for performing a particular recovery operation.

The context for deriving or evaluating a recovery system is provided by three principle criteria:

1. Probability of success of the operation, including: capsule and capsule equipment reliability, vehicle and vehicle equipment performance and reliability, probability of detection before impact, probability of successful search, reliability of communications, navigational accuracy, and probability of location of impact occurrence (not known in the present problem).

2. Time required to perform and complete the actual recovery operation from its initiation at impact, including times for: communications, impact prediction computation (where necessary), coordination, travel from vehicle station to impact location, search of an impact area uncertainty, and the actual mechanics of retrieve, some of which may take place simultaneously, others of which must take place successively.

3. Cost of the operation, including: equipment, vehicles, and personnel cost both during the actual operation and during staging periods before and after.

In the next major part of the report, to follow, the above-discussed elements are applied to the specific frame of reference pertinent to the early three-orbit missions of Project Mercury, beginning with a description of the geographical areas involved, moving through a derivation of illustrative systems, and thence to an evaluation of those systems. The means of analysis is that set forth in the foregoing general treatment of the recovery problem.

In this section are derived some additional general relationships:

1. The equipment performance and reliability which may be expected from particular detection aircraft.

2. The effect of detection time on retrieve vehicle spacing, and

3. The effect of search and retrieve vehicle spacing on the cost of the combined operations.

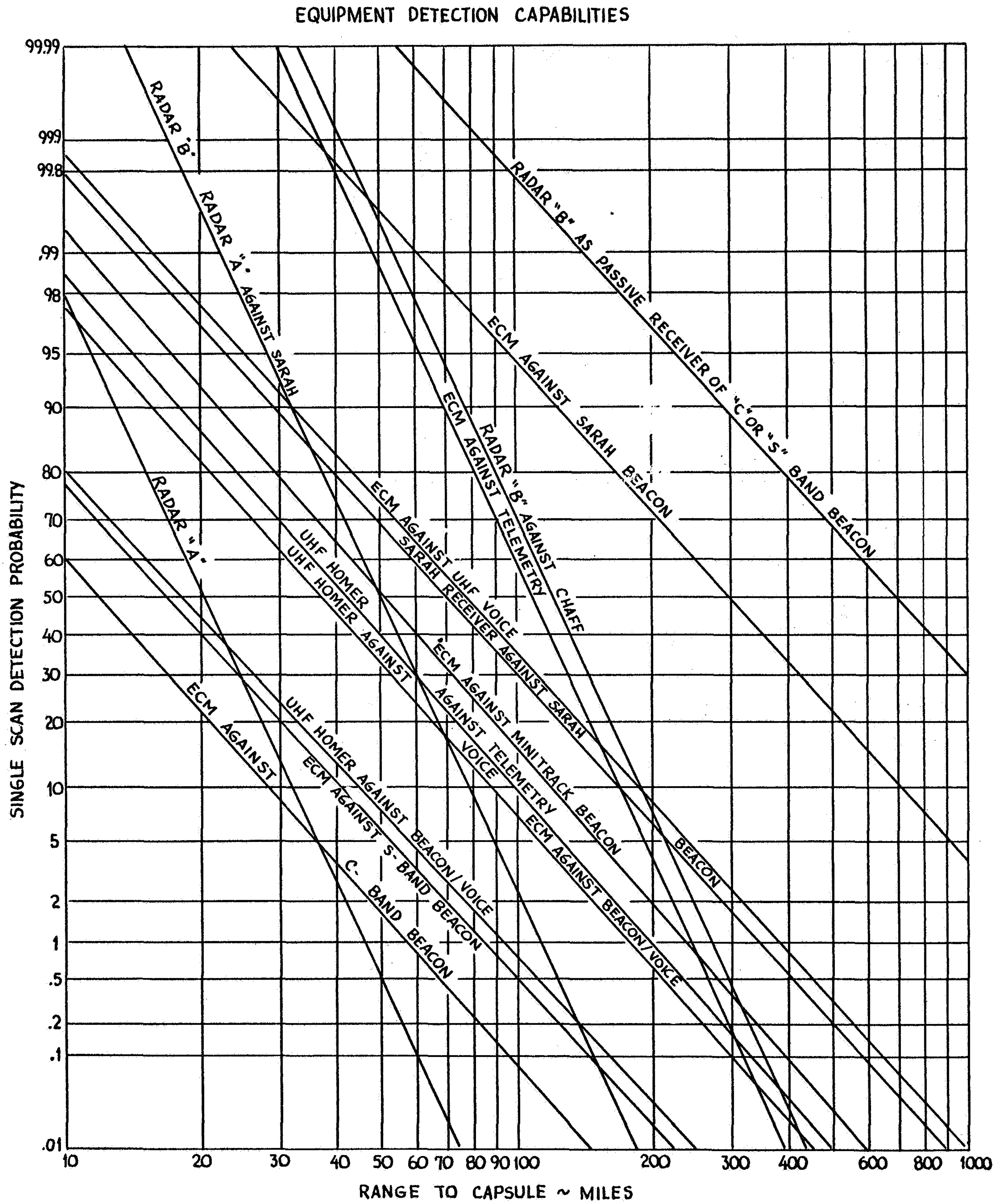

EQUIPMENT DETECTION CAPABILITIES
SINGLE SCAN DETECTION PROBABILITY
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
.5
.2
.1
.01
10
20
30
40
50
60
70
80
90
100
200
300
400
600
800
1000
RANGE TO CAPSULE ~ MILES
RADAR "B"
RADAR "A" AGAINST SARAH
RADAR "B" AS PASSIVE RECEIVER OF "C" OR "S" BAND BEACON
ECM AGAINST SARAH BEACON
ECM AGAINST TELEMETRY
RADAR "B" AGAINST CHAFF
ECM AGAINST UHF VOICE
SARAH RECEIVER AGAINST SARAH
RADAR "A"
UHF HOMER
UHF HOMER AGAINST VOICE
ECM AGAINST MINITRACK BEACON
AGAINST TELEMETRY
BEACON
ECM AGAINST C- BAND BEACON
UHF HOMER AGAINST BEACON/VOICE
ECM AGAINST S- BAND BEACON
ECM AGAINST BEACON/VOICE

FIG. 43

Detection Before Impact

It was concluded previously that visual detection outside the region of capsule incandescence is very short ranged, and that electronic detection means must be employed to assure high detection probability at reasonable distances. Performance and Reliability of the electronic equipment employed in search must be evaluated to obtain a figure of relative value for various search techniques.

Detection probability can be defined as:

$$P(d) = \frac{1}{\sqrt{2\pi\sigma}} \int_{-\infty}^{E} e^{-x^2/2\sigma^2} dx \qquad \text{Equation 19}$$

where E is excess of signal to noise plus recognition differential, in decibels, σ is standard deviation of total noise, in decibels, x is signal level.

Figure 43 shows detection probability as a function of distance from the search vehicle. Sigma is taken as six decibels, and the range to .5 probability of detection is taken from the data of Table 8 . In this figure, Radar "A" is typical of the radars aboard S2F, UF, SA-16, ZPG-1 and C54 type aircraft. Radar "B" is typical of that aboard P5M, P2V, WV-2 and PG-2W aircraft. Radar "B" is capable of receiving beacon information on "C" or "S" Bands, while Radar "A" is X-band radar. The curves titled "S-band beacon" and "C-band beacon" list ranges to these beacons with ECM Equipment installed aboard most military aircraft listed above. However, Figure 43 shows that far better ranges are obtained by employing radar equipment as passive beacon receivers. It is unfortunate that although most of the available Navy aircraft have X-band equipment there is no such beacon in the capsule. Consideration should be given to including X-band beacon equipment aboard the capsule if vehicles with X-band equipment are to be employed.

These probabilities of detection must be degraded by consideration of the reliability of the search equipment. The question of reliability has been considered in detail, and Figure 30 shows this reliability as a function of time that equipment has been operating. Since the detection vehicle can warm up its equipment and have it available by the time of expected impact, it need not be kept operating longer than is necessary to detect. For vehicles located close enough to detect the capsule before impact, operating times in the order of one half hour or less are attainable. The values of equipment reliability used in the analysis for detection before impact are, then:

- Radar; 0.975
- UHF receivers; 0.99
- ECM receivers; 0.9965

In the event that the capsule is not detected before impact, the electronic equipment reliability will continue to fall off with increase in search time.

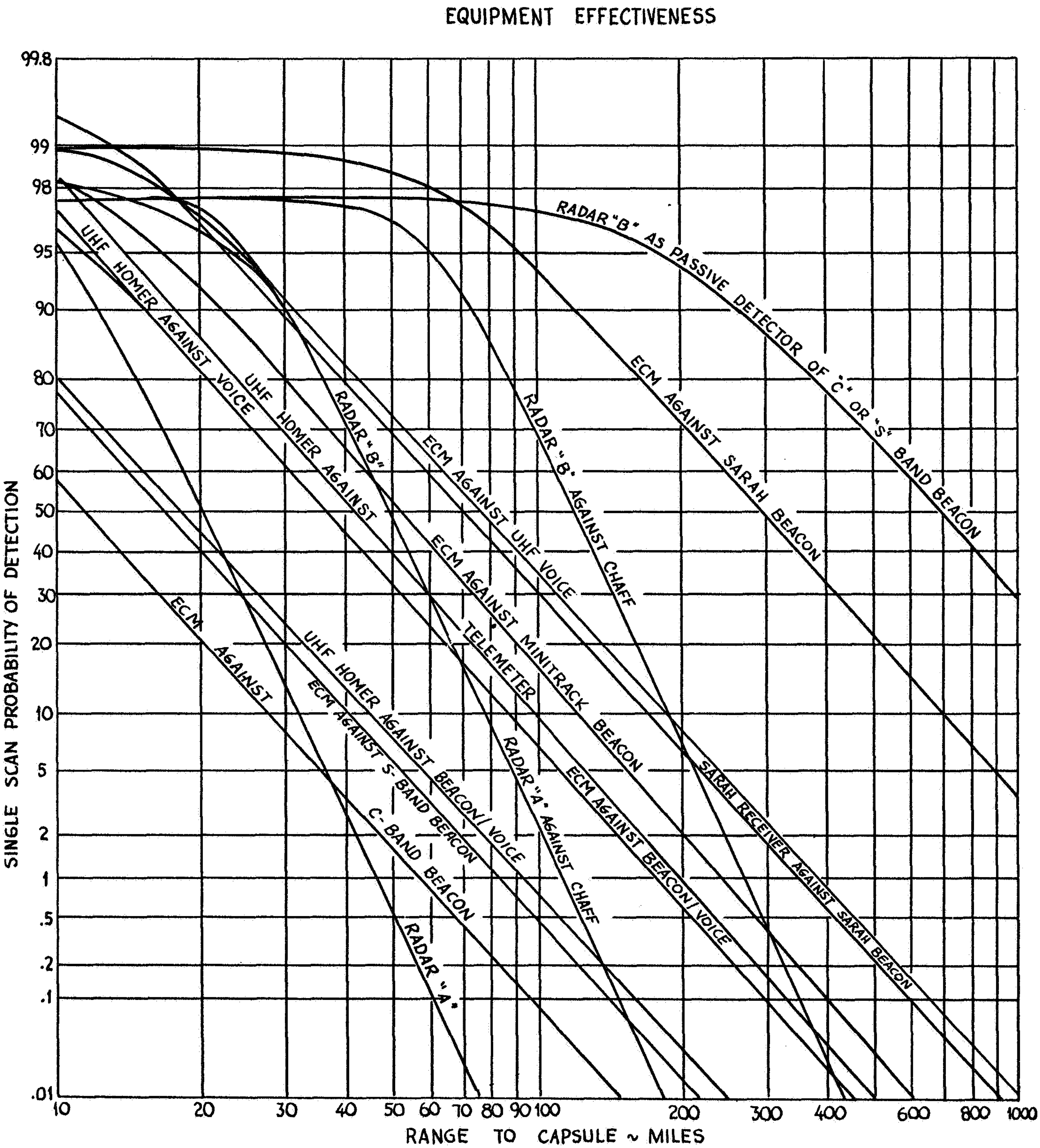

EQUIPMENT EFFECTIVENESS
SINGLE SCAN PROBABILITY OF DETECTION
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
.5
.2
.1
.01
10
20
30
40
50
60
70
80
90
100
200
300
400
600
800
1000
RANGE TO CAPSULE ~ MILES
RADAR "B" AS PASSIVE DETECTOR OF "C" OR "S" BAND BEACON
ECM AGAINST SARAH BEACON
RADAR "B" AGAINST CHAFF
ECM AGAINST UHF VOICE
RADAR "B"
UHF HOMER AGAINST
UHF HOMER AGAINST VOICE
ECM AGAINST MINITRACK BEACON
TELEMETER
SARAH RECEIVER AGAINST SARAH BEACON
ECM AGAINST BEACON/VOICE
RADAR "A" AGAINST CHAFF
UHF HOMER AGAINST BEACON/VOICE
ECM AGAINST S-BAND BEACON
C-BAND BEACON
ECM AGAINST
RADAR "A"

FIG. 44

Figure 44 shows probability of detection before impact modified by these values of equipment reliability. This figure shows that at longer detection ranges, the highest detection probabilities are attainable when radar equipment is used to receive beacon signals from the capsule. Higher detection probabilities are attainable at modest distances, when the effects of combinations of various detection devices aboard search aircraft are considered. Earlier, this report contained a tabulation of some of the equipment carried aboard various aircraft, and from this tabulation, five basic detection vehicle types can be studied. These types, and the aircraft included in each, are:

Type one: Carries Radar "B", UHF homing equipment and ECM homing equipment. Aircraft included are P5M, P2V, WV-2 and ZPG-2W.

Type two: Carries Radar "A", UHF homing equipment and ECM equipment. The S2F is of this type.

Type three: Carries Radar "A" and UHF homing equipment. The UF is of this type.

Type four: Carries Radar "A" and ECM homing equipment. The ZS2G-1 airship is of this type.

Type five: Carries Radar "A", UHF equipment and a SARAH Receiver. Aircraft included are SA-16 and C54 types.

Figure 45 shows probabilities of detection before impact for the vehicles in these groups when all capsule aids are working properly.

These probabilities of detection are all for single scan with all equipment. They can be considerably improved by increasing the number of scans. Figure 10 shows the improvements possible as a function of the number of scans available while the target is within range.

Figure 44 shows the advantage in range obtainable by employing radar as a passive beacon receiver. The aircraft capable of receiving the C-orS-band beacon signals have a very large probability of detection out to line of sight, when these aids are operating. As a result of the probability of detection figures shown here, assuming 7 scans on the capsule, the aircraft can be rated in effectiveness. The following table gives relative numbers of vehicle types which are required to attain 95% probability of detection along a track of arbitrary length. Line of sight for fixed wing aircraft is taken at 150 miles, while for lighter-than-air ships, it is considered to be 45 miles, since they operate at lower altitudes.

VEHICLE SINGLE SCAN EFFECTIVENESS

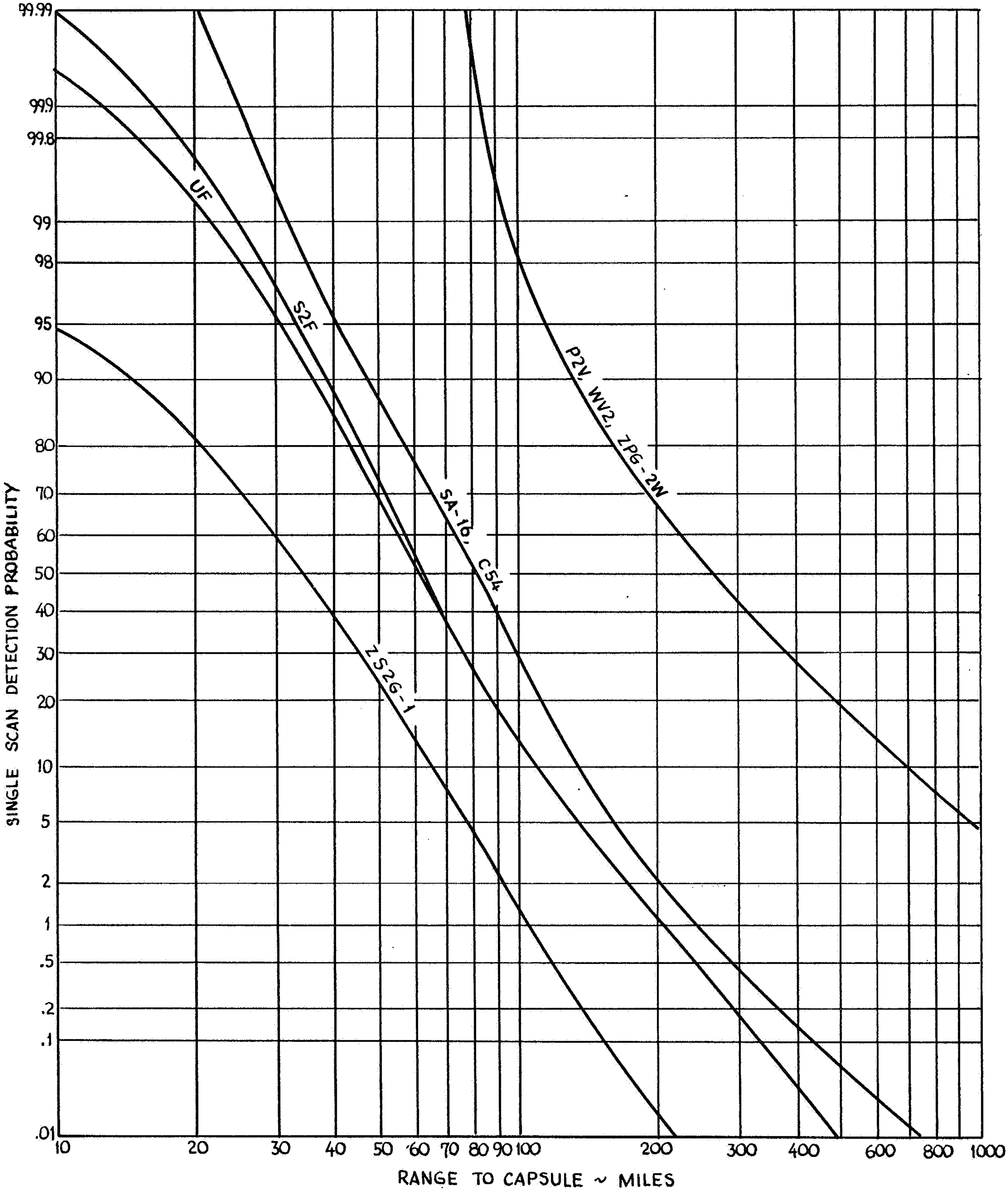


FIG. 45

Search Vehicle	Relative Number of Vehicle
P2V, WV-2	1
S2F, UF	2.05
SA-16, C54	1.58
ZPG-2W	3.33
ZS2G-1	3.49

The above table considers all the capsule aids to be available. The following table shows the degradation to system effectiveness when the only capsule aid available is chaff, and when no capsule aids are available.

Search Vehicle	Relative Number of Vehicles	
	Chaff Alone Available	No Aids Available
P2V, WV2	1.07	2.63
S2F, UF, SA-16, C54	2.63	7.15
ZPG-2W	3.33	3.33
ZS2G-1	3.49	7.15

Retrieve

Retrieve vehicles have three requirements; to proceed to the impact area, pick up the pilot and capsule, and provide aeromedical services for the pilot, all within stated time limitations. The ability of vehicles to retrieve the capsule and provide medical attention have been discussed in previous sections. Of those vehicles capable of retrieving the capsule, those which have the higher velocities have been shown to be most promising. The previous section contains a discussion of cost and number of vehicles required in various areas, as function of vehicle velocity.

For any given velocity vehicle, there is only a small range in the numbers required to operate in a given area. This range is a function of the time required for the detecting vehicle to vector the retrieve vehicle to the immediate area of the target. If the detection vehicle locates the target immediately, the maximum spacing can be obtained. This spacing can easily be seen to be:

$$L_{max.} = 2\sqrt{V_r^2 \, T_t^2 - (W/4)^2}$$

where $L_{max.}$ = maximum spacing between vehicles along area centerline

V_r = velocity of retrieving vehicle

T_t = total time required for recovery

W = width of impact area

If the detecting vehicle does not vector the retrieve vehicle because of difficulty in detection or short range of detection in areas of non-continuous detection coverage, then the minimum spacing is:

$$L_{min} = 2\, V_r t_{s(max)} = 2\, (V_r\, T_t - W/2) \qquad \text{Equation 20}$$

where $t_{s(max)}$ = maximum time spent searching for capsule after impact.

Since the number of vehicles to cover an area can be expressed in most areas by:

$$N = \frac{D}{L}$$

where: D = length of area
L = vehicle spacing

then the ratio of number of vehicles at maximum spacing to number at minimum spacing is:

$$\frac{N(L_{max.})}{N(L_{min.})} = \frac{D/L_{max.}}{D/L_{min.}} = \frac{V_r\, T_t - W/2}{\sqrt{V_r^2\, T_t^2 - (\frac{W}{2})^2}} = \left[\frac{1 - \frac{W}{2V_r\, T_t}}{1 + \frac{W}{2V_r\, T_t}}\right]^{\frac{1}{2}}$$

That this ratio is generally close to one can be seen by a practical example

Let W = 40 miles
V_r = 25 knots
T_t = 6 hours

Then

$$\frac{N(L_{max.})}{N(L_{min.})} = .89$$

The above example shows that under extremes of times to detect the capsule, the number of retrieve vehicles does not vary by more than about 11% for the values given.

From equation 20 the maximum allowable search time can be seen to be:

$$t_{s(max)} = T_t - \frac{W}{2V_r}$$

For the example given above, maximum search time is, then, 5.8 hours. This time represents as much as 870 miles of additional spacing for a search vehicle traveling at 150 knots. In this case the possibility of trading search time for system cost must be considered. Given previously is a discussion of this trade-off, and applications to the specific recovery areas of high impact likelihood are considered below.

Example of Reduced Detection Vehicle Spacing

What is the vehicle spacing which will minimize the operating cost of the combined search and retrieval systems? Consider the eastern end of Area 2, defined in Section II. The detection vehicle is assumed to be the P5M; the retrieving vehicle the destroyer (DD). The width of the track to be monitored is 40 miles. The radius of the detection equipment is 35 miles. The P5M's are considered to require 1.5 hours of search time after coming within range of the capsule to locate it and direct the retrieving vehicle towards it.

The operating cost of a P5M station at a radius of 610 miles, maintained for 4 hours, is seen to be \$690 per hour per 200 miles of track in Figure 37 . This cost is predicated on the need for 0.826 aircraft per 200 miles of track (as shown in Figure 36c); the operating cost of one P5M is therefore \$690/0.826 = \$835 per hour on station.

If the destroyers are on station for 4 hours daily and their entire daily operating cost is to be allocated to the recovery program, their cost per hour on station is 24 hours/4 hours x \$447 per hour = \$2,682 per hour on station. The cost ratio (C_d/C_r) is therefore 835/2,682 = 0.311. For this cost ratio, Figure 41 indicates that minimum combined system cost will be achieved if the travel time permitted the detection vehicles is 48% of the dash time. This is 2.76 hours for a dash time of 5.75 hours.

With this much travel time, the number of detection vehicles per 200 miles of track is

$$N_d = \frac{L/2}{V_d\, t_t + \sqrt{L_s^2 - (\frac{W}{2})^2}} = \frac{200/2}{(150)\ (2.76) + \sqrt{(35)^2 - (\frac{40}{2})^2}} = 0.226$$

Stated in another way, a single detection vehicle can monitor 885 miles of track.

If the retrieving vehicles were able to proceed directly to the capsule immediately on impact, the number of vehicles required per 200 miles of track would be:

$$N_{r_o} = \frac{L/2}{\sqrt{V_r^2\, t_d^2 - (\frac{W}{2})^2}} = \frac{200/2}{\sqrt{(25)^2\ (5.75)^2 - (\frac{40}{2})^2}} = 0.703$$

On the other hand, if the detection vehicle is permitted 2.76 hours of travel time and 1.5 hours of search time before it can vector the retrieving vehicle, the number required per 200 miles of track is increased to:

$$N_r = \frac{L/2}{V_r(t_t+t_f) + \sqrt{V_r^2(t_d-t_t-t_f)^2 - (\frac{W}{2})^2}}$$

$$= \frac{200/2}{(25)\ (2.76 + 1.5) + \sqrt{(25)^2\ (5.75 - 2.76 - 1.5)^2 - (\frac{40}{2})^2}} = 0.724$$

This represents an increase of about 3% in the number of retrieving vehicles, a negligible amount when the practicalities of assigning vehicles to particular areas are considered.

To determine the arrangement which would minimize the number of vehicles required, the cost ratio (C_d/C_r) is taken as 1.0. The travel time permitted the detection vehicles is 3.13 hours under these circumstances. A single P5M can monitor 980 miles of track, and the number of retrieving vehicles per 200 miles of track is 0.738, an additional 2% increase. The spacing of detection vehicles for minimum cost would therefore seem to be relatively insensitive to vehicle operating cost. For practical purposes, the minimum cost distribution of vehicles is the same over a reasonable range of vehicle cost ratios.

II RECOVERY IN HIGH PROBABILITY IMPACT AREAS

II. RECOVERY IN HIGH PROBABILITY IMPACT AREAS

GENERAL

In this section the results of the previous section are applied to the specific areas where the Mercury capsule is most likely to impact. Detailed support requirements are evolved for each area, with consideration given to area size, location and proximity to support bases. Expected environmental conditions and the limitations they may place on the operation are outlined. Numbers and types of vehicles for each impact area are recommended, considering all the recovery functions to be performed, with alternate choices noted.

Since the exact size, location, and impact probability of each impact area, as well as actual recovery techniques, are subject to change, depending on the results of continuing studies and tests by other Project Mercury contractors and the NASA, the recommendations made in this section should be considered flexible and indicative of the order of magnitude of the necessary recovery support. As details of the operation become more certain, the recommendations of this study may be adjusted to provide more precise values for numbers of vehicles, access time, limiting environmental conditions, and other factors affecting the recovery.

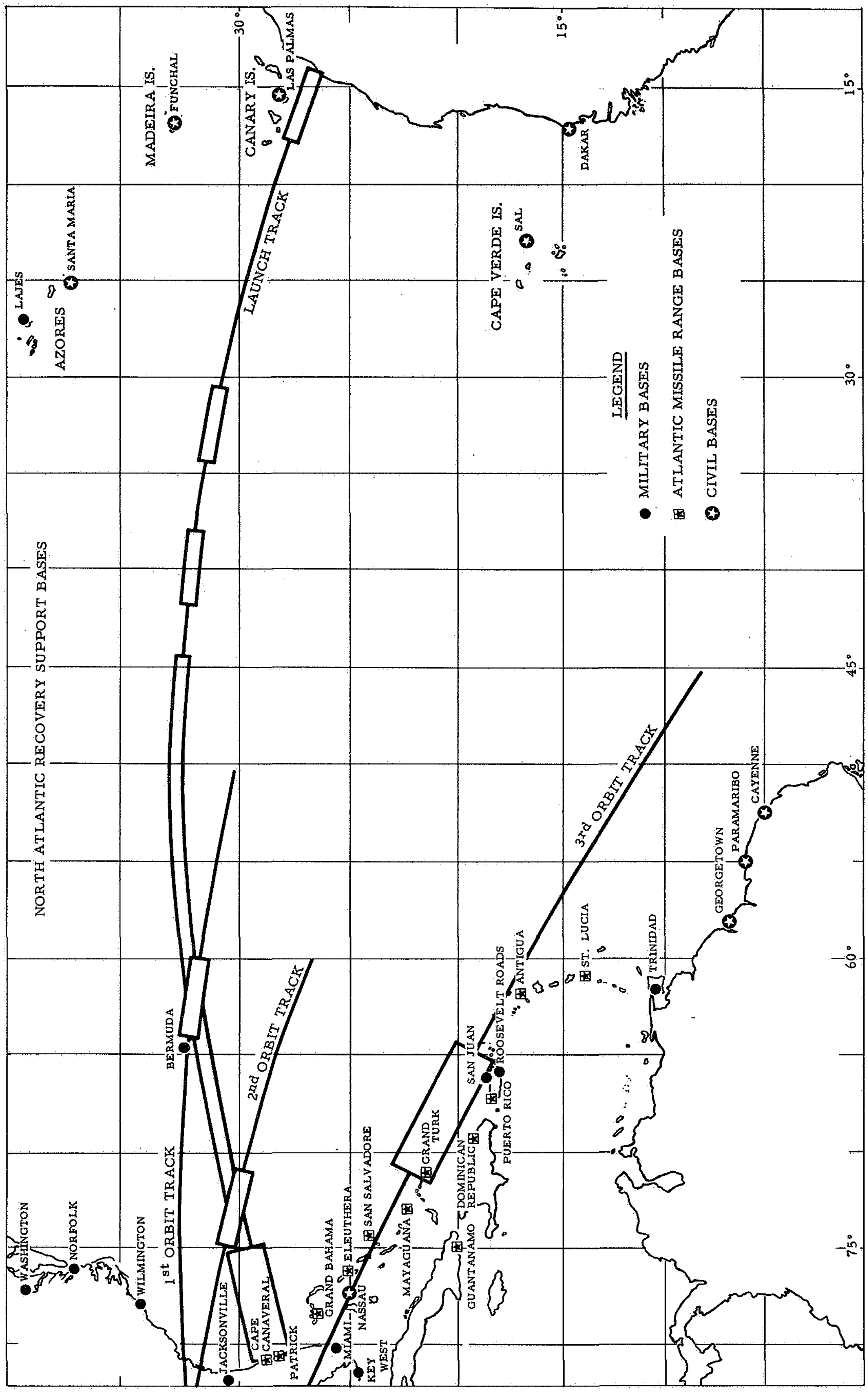

NORTH ATLANTIC RECOVERY SUPPORT BASES
LEGEND
MILITARY BASES
ATLANTIC MISSILE RANGE BASES
CIVIL BASES
LAUNCH TRACK
1st ORBIT TRACK
2nd ORBIT TRACK
3rd ORBIT TRACK
AZORES
LAJES
SANTA MARIA
MADEIRA IS.
FUNCHAL
CANARY IS.
LAS PALMAS
DAKAR
CAPE VERDE IS.
SAL
BERMUDA
WASHINGTON
NORFOLK
WILMINGTON
JACKSONVILLE
CAPE CANAVERAL
PATRICK
KEY WEST
MIAMI
GRAND BAHAMA
NASSAU
ELEUTHERA
SAN SALVADORE
MAYAGUANA
GRAND TURK
GUANTANAMO
DOMINICAN REPUBLIC
PUERTO RICO
SAN JUAN
ROOSEVELT ROADS
ANTIGUA
ST. LUCIA
TRINIDAD
GEORGETOWN
PARAMARIBO
CAYENNE
15°
30°
45°
60°
75°

FIG. 46

LOCATION AND SIZE OF IMPACT AREAS

The precise ground track and possible capsule impact areas will depend on the results of studies and tests yet to be conducted. The Project Mercury buildup program, culminating in unmanned orbit shots with capsule re-entry and pickup, will contribute much information about the size and location of the planned final recovery area as well as the various possible abort impact areas. Present estimates of these areas, however, should be sufficiently dependable to permit determination of specific recovery operational requirements without demanding extensive revision when later information becomes available.

The map given in Figure 46 shows the expected ground track of the Mercury capsule over the North Atlantic. Planned impact of the vehicle is to be at the conclusion of the third orbit, in a 120 by 400 nautical mile area north of Puerto Rico (recovery area #8, see table). An abort on the firing pad or during booster phase will result in firing of the emergency escape rocket which will lift the capsule sufficiently to allow parachute deployment and impact within a 100 x 300 nautical mile area just east of Cape Canaveral (Area #1). Extending along the launch track from the launch abort area to the mid-Atlantic, an area (#2) 40 x 1600 nautical miles represents possible capsule impact during an abort of the sustainer stage. Two other possible sustainer abort impact areas (#3 and #4), 40 x 200 nautical miles each, are located farther along the launch track. A final impact area along the launch track (#5), 40 x 200 nautical miles, is located just off the African Coast, and represents re-entry from a mission abort just after orbit injection attempt (if unsuccessful). Flight emergency recovery areas of 50 x 210 miles each are located at the intersections of the launch track with the ends of the first (area #6) and second (area #7) orbit tracks. The three orbits of the capsule fall between $32\frac{1}{2}°$N and $32\frac{1}{2}°$S latitude.

Mercury Impact Area Designation

Number	Size	Location
1	100 x 300 NM	Pad or Booster Abort - From Cape Canaveral Eastward
2	40 x 1600 NM	Sustainer Abort - From Area #1 to Mid-Atlantic Along Launch Track
3	40 x 200 NM	Sustainer Abort - Just East of Area #2 Along Launch Track
4	40 x 200 NM	Sustainer Abort - Just East of Area #3 Along Launch Track
5	40 x 200 NM	Injection Abort - Just South of the Canary Islands along Launch Track

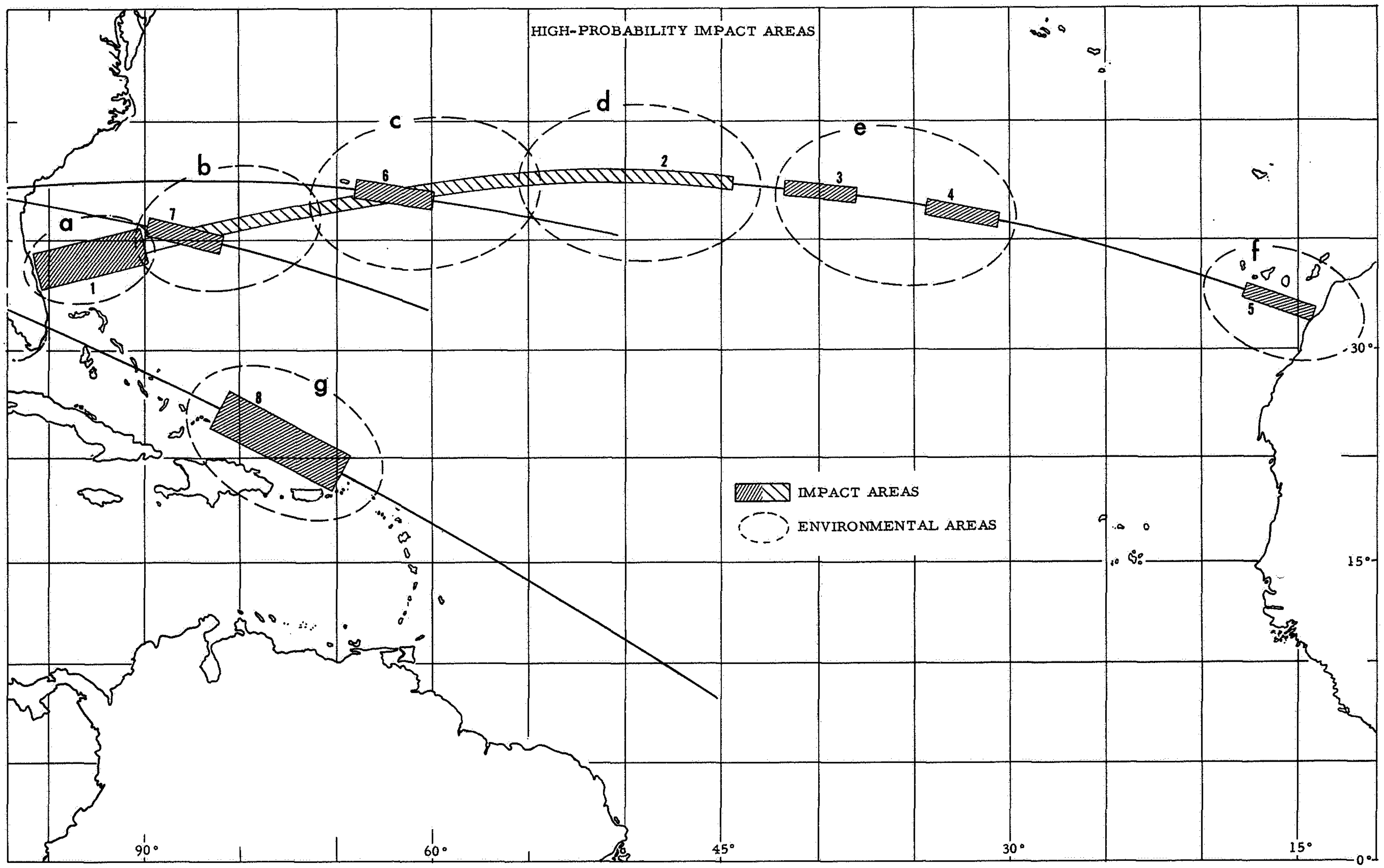

HIGH-PROBABILITY IMPACT AREAS
a
b
c
d
e
f
g
1
2
3
4
5
6
7
8
IMPACT AREAS
ENVIRONMENTAL AREAS
90°
60°
45°
30°
15°
0°
30°
15°

FIG. 47

Mercury Impact Area Designation (Cont.)

Number	Size	Location
6	50 x 210 NM	1st Orbit Landing - Just East of Bermuda where 1st Orbit Track crosses Launch Track
7	50 x 210 NM	2nd Orbit Landing - Just East of Area #1 where 2nd Orbit Track crosses Launch Track
8	120 x 400 NM	3rd Orbit Landing - North of Hispaniola and Puerto Rico along 3rd Orbit Track

Figure 46 illustrates the location of the capsule track in the North Atlantic, the locations of the various high-probability impact areas, and the area designations. The numerals refer to the impact areas themselves, and the letters indicate areas of similar environmental conditions, as discussed in the following section.

Figure 47 shows the locations of possible bases which may be used for support of the recovery forces. The relationships between the various bases and recovery areas are discussed in detail in later sections of the report.

WEATHER AND ENVIRONMENT

The capsule recovery will be strongly influenced by the environmental conditions during the operation. Heavy cloud cover would preclude visual observation and tracking of the capsule during re-entry. High sea states would create difficulties in many areas - some of the support vehicles may be unable to maintain station or search properly, the bobbing capsule may have adverse affects on the occupant, shielding by the waves would degrade both visual and electronic search, and capsule pick-up would be difficult. Other environmental factors of importance include visibility, wind velocity (closely allied to sea state), and ocean currents. Water depths are important both from the standpoint of navigational hazards (especially in the final impact area), and the capabilities of the SOFAR bomb location techniques.

Accurate weather and sea state prediction must be available to Project Mercury well in advance to the actual launching. Members of the prediction section of the Navy's Hydrographic Office estimate that wave heights for any area in the North Atlantic can be predicted to within one foot, up to 48 hours in advance, with 85% accuracy. Weather prediction was felt to be reliable up to 48 hours in advance, for the areas of interest to this study. Since preparation for the capsule recovery, including dispatching ships to the middle Atlantic, will require more than 48 hours, longer range forecasts must be utilized. Preparations for the launching must consume weeks and months before the shot. Because of the obvious difficulty of providing detailed weather forecasts of significant accuracy so far in advance, the launching should be planned for that period of the year during which the probability of favorable conditions is the highest.

Table 22 shows the probability of winds equal or less than force 4 (16 knots) and force 5 (21 knots) for the various impact areas (note the area breakdown) and for each month of the year. These wind velocities were chosen because they represent about the maximum values which can be tolerated by the recovery forces without excessive difficulty. Wave heights associated with 16- and 21-knot winds are about 6 and 9 feet, respectively, and the table may be used to indicate the approximate probability of not exceeding these sea states.

Environment Area Designations

Area	Location
(a)	Pad or Booster Abort - Cape Canaveral (Recovery Area #1)
(b)	Sustainer Abort - West Atlantic (Area #7 and West third of Area #2
	2nd Orbit Abort - West Atlantic (Area #7 and West third of Area #2
(c)	Sustainer Abort - Bermuda (Area #6 and Central third of Area #2)
	1st Orbit Abort - Bermuda (Area #6 and Central third of Area #2)
(d)	Sustainer Abort - West Central Atlantic (East third of Area #2)
(e)	Sustainer Abort - East Central Atlantic (Areas #3 and #4)
(f)	Injection Abort - Canary Islands (Area #5)
(g)	Final Impact - Puerto Rico (Area #8)

These Areas are illustrated in the map of Figure 46.

Table 22

Percent Probability of Force 4 Wind or Less (≤16 Kts.)

Month / Area	J	F	M	A	M	J	J	A	S	O	N	D
(a)	75	72	72	78	89	94	94	93	88	78	79	75
(b)	74	69	71	82	91	96	96	93	88	81	72	82
(c)	57	47	60	73	86	85	93	92	82	70	63	58
(d)	47	33	36	66	72	77	92	89	73	67	57	46
(e)	58	52	64	73	80	93	86	94	83	74	65	64
(f)	74	73	72	75	78	74	58	58	80	87	78	77
(g)	72	82	80	90	88	90	84	88	88	87	82	79

Percent Probability of Wind Force 5 or Less (≤21 Kts.)

Month / Area	J	F	M	A	M	J	J	A	S	O	N	D
(a)	90	89	90	94	98	99	98	98	96	91	93	91
(b)	90	85	86	94	98	99	99	98	96	93	89	93
(c)	76	63	77	87	96	97	98	98	95	90	82	76
(d)	70	55	57	83	88	92	98	97	89	88	78	64
(e)	74	72	81	86	93	98	99	98	93	89	83	80
(f)	93	91	89	92	94	91	87	85	95	98	93	93
(g)	91	95	95	99	99	99	97	96	98	94	95	95

Examining the tables, it may be noted that there are noticeable seasonal variations in wind speed for each area, and sizable differences between areas. In general, the best chance for low wind velocity occurs in June, July, and August, and the strongest winds occur in December, January, February, and March. The exception to this trend is the injection abort area near the Canaries (f), where the winds blow hardest in July and August and least in September and October. The strongest winds during the Winter and Spring months occur in the middle Atlantic (c, d, and e) and are sufficient to seriously hamper recovery efforts during these seasons. On the basis of expected wind velocities, then, preferable time for the planned launch would be from May through September, with June probably the optimum month.

As mentioned in a previous section of this report, a hazard exists where the wind is insufficient to blow the parachute clear, and the canopy settles over the capsule. Percent probabilities of low wind velocities for each month and area are shown in Table 23 . It may be seen that wind speed is less than 6 knots in many of the areas for a large proportion of the time, especially in summer. Occurrence of wind speed of only 4 knots or less is significant for the Middle Atlantic areas in summer. Furthermore, the hazard of having the parachute cover the capsule is possible even during generally higher wind conditions for momentary lulls can occur as the capsule lands.

Table 23

Percent Probability of Force 2 Wind or Less (≤6 Kts.)

Month / Area	J	F	M	A	M	J	J	A	S	O	N	D
(a)	21	21	16	22	26	33	37	40	34	28	22	22
(b)	28	22	21	27	39	45	47	41	42	27	23	25
(c)	16	7	14	26	34	29	42	45	32	23	19	12
(d)	8	5	9	15	19	21	37	31	20	15	11	8
(e)	16	17	17	24	32	38	49	55	36	27	24	22
(f)	21	21	23	22	22	18	8	8	23	32	27	25
(g)	13	18	18	22	17	17	12	14	28	32	31	26

Percent Probability of Force 1 or Less (≤4 Kts.)

Month / Area	J	F	M	A	M	J	J	A	S	O	N	D
(a)	6	6	5	7	9	12	12	15	11	10	7	7
(b)	7	7	7	10	15	19	18	14	15	11	9	8
(c)	5	2	5	9	17	14	15	22	14	8	6	4
(d)	2	2	3	5	6	7	12	10	7	6	2	3
(e)	5	7	6	9	12	15	21	29	16	8	9	7
(f)	7	7	6	7	7	5	2	2	6	12	9	8
(g)	4	6	4	5	6	3	2	2	9	9	8	9

Other weather conditions also appear to be generally superior in Summer to those in the Winter. Surface water temperatures are warmest in Summer, reducing possible exposure hazard to the pilot. Surface visibility is excellent in all areas, especially in the final impact area near Puerto Rico (g); Summer appears slightly better than Winter, although the difference is slight.

Table 24 lists the mean cloud cover, that is, the average percentage of the sky covered with clouds, for each area and for each month. Considering all areas, least mean cloud cover may be expected in June, July and August, with the maximum cloud cover appearing in November to March.

Table 24

Percentage Mean Cloud Cover

Month / Area	J	F	M	A	M	J	J	A	S	O	N	D
(a)	44	44	46	41	33	34	41	46	48	46	48	51
(b)	42	48	44	36	35	31	28	31	31	53	48	39
(c)	56	66	56	59	55	45	26	28	33	46	59	65
(d)	69	76	75	66	64	55	36	26	43	65	64	70
(e)	57	53	53	49	41	39	25	23	28	39	53	54
(f)	24	24	25	26	28	26	29	20	19	24	28	26
(g)	26	21	21	23	38	28	25	24	25	26	25	29

Mean cloud cover during the Summer months is between 20% and 30% for the final impact area near Puerto Rico (g) and the injection abort impact area near the Canaries (f), somewhat higher in the mid-Atlantic areas (c,d, and e), especially in June, and from 30% to 50% near Cape Canaveral (a and b). Solid overcast must not be considered impossible for any of these areas, even in Summer, although it would be unlikely for all but the Middle Atlantic region.

Ocean currents in all areas average around 1/2 knot, except that the Gulf Stream off Cape Canaveral (area a) exceeds 2 knots. Except in the Gulf Stream, the capsule drift will probably be determined largely by the wind, with relatively little influence from the current.

The annual hurricane season in the Caribbean begins in June and lasts until November. This will necessitate possible holds in the launching schedule if tropical storms develop during preparations for the launch. In spite of this, it is felt that the probability of overall favorable conditions during the operation is substantially higher in Summer than during the remainder of the year. Occurrence and duration of gale force winds, for example, is much less in Summer than in Winter, particularly in the mid-Atlantic. Recovery forces will provide weather monitoring and reporting functions so that the presence of any unfavorable conditions requiring launch delay can be detected.

It is unrealistic to expect or require ideal weather in all the possible impact areas before launching the capsule. On the other hand, severe weather which would make recovery from any area extremely difficult should be cause for delay until better conditions prevail. Probably the most important single item, and perhaps the only critical one, is the wind velocity encountered, both during vehicle deployment to assigned areas, and during the actual search and recovery for ease of operation. High winds create high sea states with short wave period, white caps, blown spray, and generally hazardous conditions for all recovery forces. Although high wave heights can occur in ocean areas distant from where they are generated, even though the local wind is calm, the condition of the sea usually is one of long swells which is much more preferable to a wind-whipped choppy sea. It would be desirable to operate in

winds of less than force 4 (16 knots), but to avoid a high risk of postponement due to unfavorable weather, satisfactory recovery capability with winds up to force 5 (21 knots) is highly desirable. This corresponds to a wave height of 9 feet, as previously mentioned. Any measured or predicted winds in excess of 21 knots for any of the recovery areas should be cause for postponing the launch until conditions improve.

The Mid-Atlantic Ridge separates the North Atlantic into two basins of roughly 3 miles depth. The water depth over the ridge is roughly 2 miles. Local variations are considerable, but the only areas where shoal water is a navigational hazard are in the immediate vicinity of Bermuda and the Canary Islands, and to a greater extent, in the final impact area. In the latter area, shoals occur North of Hispaniola which ocean vessels must navigate with caution.

DEFINITION OF ACCESS TIME

The term "Access Time" refers to and is a measure of the time required to recover and rescue the occupant of the Mercury manned capsule. A particular definition has been established for use in this study:

> Access Time is the time from capsule impact in the sea to pick-up of the capsule by a vehicle large enough so that the capsule may be hoisted all or part way into or onto the vehicle and the occupant removed while the vehicle is returning to base. It is further stipulated that the recovery or retrieve vehicle be large enough to carry a medical and interrogation team and to permit rendering of (as a minimum) first aid treatment on board. In the event that pick-up is performed by a vehicle not able to fulfill this definition, access time shall be understood to include delivery of the capsule by the pick-up vehicle to a properly qualified larger vehicle or land base.

Access time includes a 5 minute period immediately after impact to allow for communications, impact point prediction, and transmittal of instructions; transit time for retrieve vehicles to reach the impact point from their respective station locations; and a 10 minute period just prior to pick-up to allow for maneuvering for proper approach and for the mechanics of the actual pick-up operation. In addition, it is assumed that location of the capsule by a search aircraft must precede arrival of the retrieve vehicle.

NUMBER OF VEHICLES REQUIRED
VS
RADIUS COVERAGE PER VEHICLE

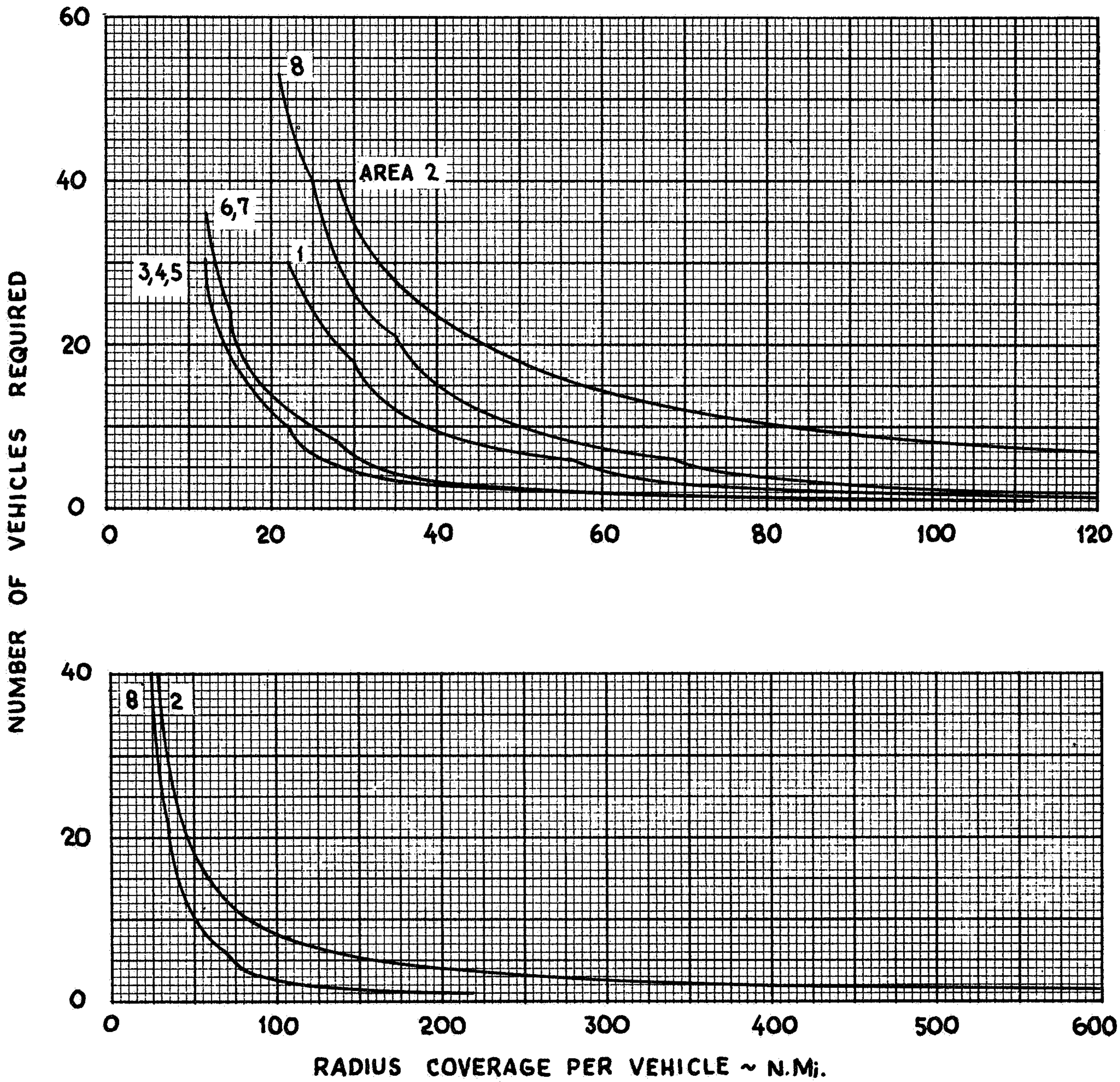


FIG. 48

VEHICLE DEPLOYMENT

The selection of a vehicle deployment complex for the Mercury manned capsule recovery problem is a several step process. As a beginning, it is a simplification to visualize a deployment complex as an array of circles, each representing the area coverage of one vehicle or vehicle station. This array may be made up by disposing the centers in a line or in a triangular or rectangular pattern. It may be shown that for a large area to be filled by small circles, the centers should be disposed at the corners of equilateral triangles. It may also be shown that as the size of the circles approaches the dimension of the area to be filled, the triangular array tends to give way to the rectangular array. The reason is that the spacing of centers may be varied between width and length so as to fit the area, whereas the equilateral triangular array is fixed in proportions, width vs length.

The above principle has been applied to each of the high probability areas to determine the number of vehicles required as a function of the radius of the area coverage circle; the results are presented in Figure 48 . This figure discloses a rapid increase in numbers required as the radius coverage is reduced, indicating the advantages in over-all deployment economy of attaining large radii of coverage per station. The breaks in the curves occur at the radii at which the array changes from a single row of vehicles to two rows, from two rows to three, etc. In the lower portion of Figure 48 , the curves for Areas 2 and 8 are shown to reduced radius scale so as to include the radius values for which low numbers of vehicles would be required.

Retrieve Vehicles

Radius coverage may be made up of vehicle speed multiplied by time, access time for example. This is the case for retrieve vehicles, but not generally for search vehicles (as discussed below). Adopting this approach for retrieve vehicles, the variation in the number of vehicles required with access time and with vehicle speed is shown in Figure 49 for abort areas (Areas 1-5) and in Figure 50 for orbit landing areas (Areas 6-8). The premium which may be placed on speed in the interests of low numbers of vehicles required is quite evident, as is the impracticality of obtaining short access time without recourse to high speed. These figures show quite forcefully one of the advantages which would accrue to a recovery system using fixed wing aircraft for recovery pick-up, the advantage of short access time coupled with small numbers of vehicles required.

The access times of 3 hours in Areas 1 and 5, and 6 hours in Areas 2 through 4 suggested by NASA do not appear unreasonable, provided that 15 knot vessels are not relied upon, since the requisite numbers of vehicles are not large; access time in the orbit landing Areas 6 through 8 have been kept as variables to be investigated. From Figure 50, it is apparent that access times of less than 3 hours may not be of practical attainment, especially in Area 8, unless relatively high vehicle speeds can be obtained, or the expected impact area reduced. An access time of 3 hours does, however, seem reasonably attainable. It should be noted that these stated access times represent maximum values occurring at points (within the monitored area) most distant from a retrieve vehicle; throughout the greater part of the area, access time would be considerably less.

NUMBER OF RETRIEVE VEHICLES REQUIRED
VS
ACCESS TIME
ABORT AREAS

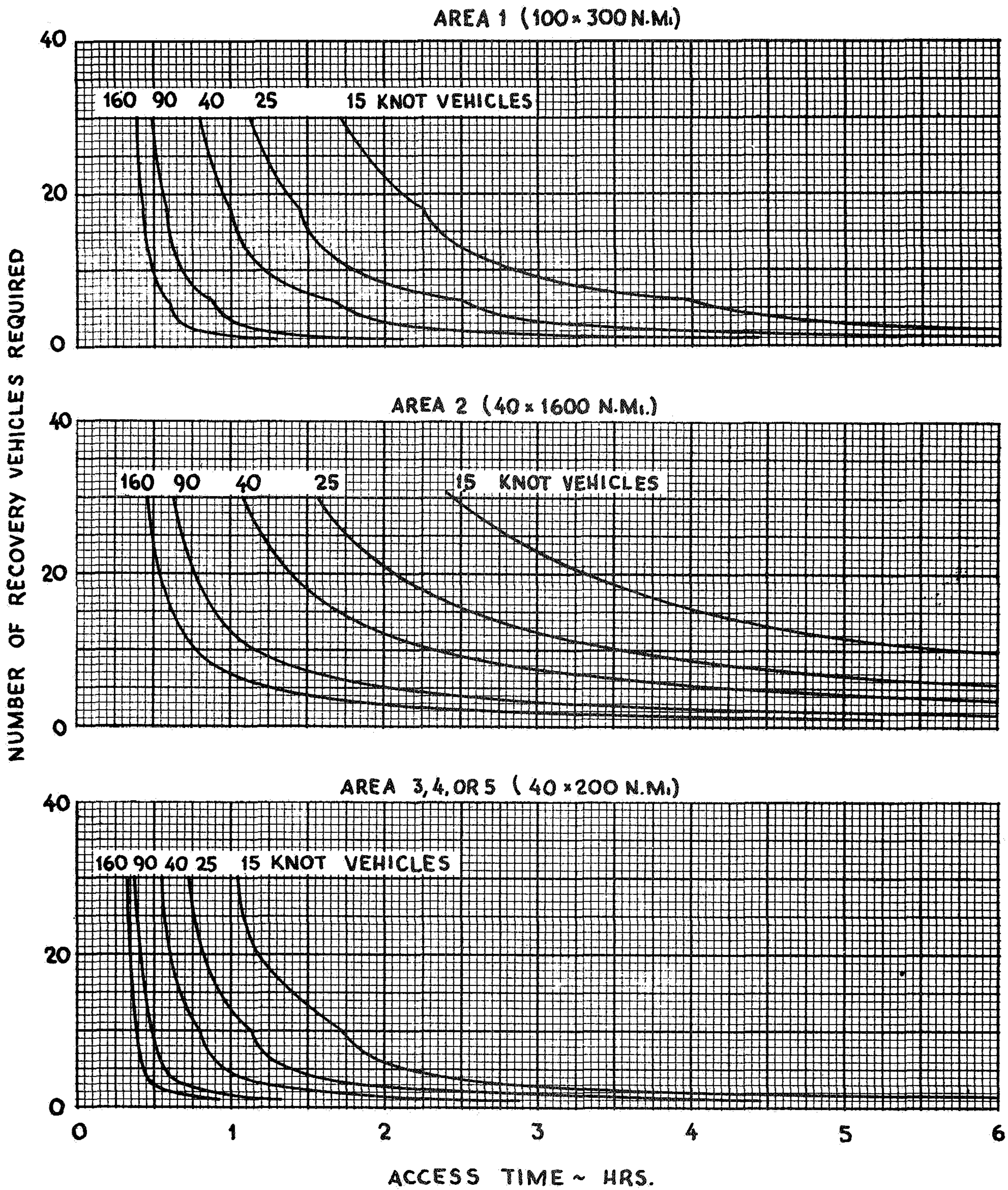


FIG. 49

NUMBER OF RETRIEVE VEHICLES REQUIRED
VS
ACCESS TIME

ORBIT LANDING AREAS

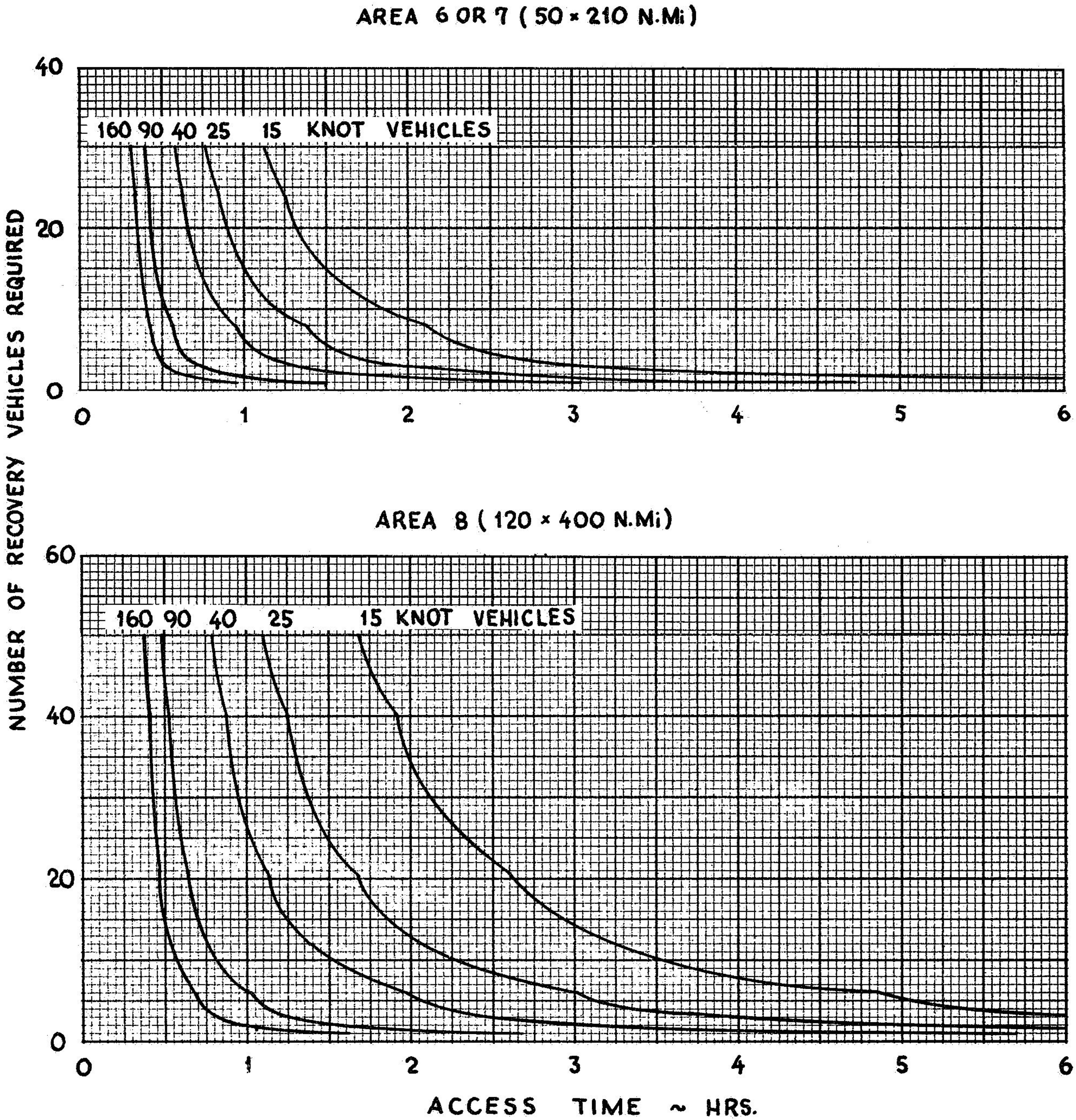


FIG. 50

Thus far, the discussion of vehicle deployment has revolved about consideration of each area as an individual entity, without regard to its geographical location or proximity to other areas. Since Area 1 is followed immediately by Area 2, and since Areas 6 and 7 are for the most part included within Area 2, a certain amount of two-way coverage may be expected. Secondly, roughly 1.5 hours may be used for redeployment of vehicles in Area 2 to Area 6, and 3 hours for Area 7, bringing in further possibilities of two-way coverage. Thirdly, portions of Areas 1,2,5,6, and 8 lie close enough to land to permit use of helicopters, with their relatively high speed, for retrieve of the capsule. In addition, the discussion has thus far considered use of only one vehicle type at a time.

In the actual, overall operation, the proximity of one area to another and to land bases and the possibility of mixing vehicle types must be considered. In doing so, any of a number of precepts can be employed. In order to establish a bench mark for comparison among various levels of effort and area coverage, the idea of a minimum acceptable system has been adopted as a basis for deriving a preferred vehicle complex and a series of alternate possibilities. Once the minimum is established, the penalty in terms of numbers of vehicles required (and the corresponding cost) to provide additional or duplicate coverage can be evaluated in a proper context. Each of the vehicle complexes selected for illustration is, then, a minimum system in the sense that it does not provide duplicate coverage, or vehicle back-up required for over-all system reliability.

In putting together several illustrative retrieve vehicle complexes, several factors were considered in addition to those already discussed:

1) In order to provide <u>land</u> pick-up capability where impact in rough areas is possible, helicopters would be most desirable: the appropriate locations are Cape Canaveral, Bermuda, and the Canary Islands, and to a lesser extent, Area 8.
2) Airships would be next in desirability in such circumstances.
3) Since the HUS and H-21 helicopters cannot hoist the capsule and remove the occupant after pick-up but must carry the capsule as a suspended load, access time should include the return portion of a recovery flight; a return flight time restriction of approximately 1.5 hours was imposed, equivalent to an operating radius of about 100 n. mi. including allowances for a 20 knot wind. At this radius, the access time would be about 3 hours. The HUS and H-21 are considered interchangeable: the operational radius value selected is approximately the capability of each using basic fuel capacity and no extra fuel.
4) Since the HR2S can hoist the capsule and remove the occupant, access time need not include the return flight, nor need the return flight duration be limited. Therefore, the full radius capability may be utilized; including allowances for a 20 knot wind, the radius is approximately 130 n.mi. and the access time about 2 hours. The HR2S can be used anywhere the HUS is specified as a minimum, and would be preferred in any case because of its superior performance and recovery capability.

5) The suggested access times of 3 hours in Areas 1 and 5 and 6 hours in Areas 2 through 4 are adhered to, and an access time of 3 hours in the orbit landing Areas 6 through 8 is assumed for illustrative purposes: it should be noted that these are maximum time values and that throughout most of each area the achieved access times would be substantially less.

6) Ships are selected on the basis of operational speed, and are not specified as to type in this section. However, of the 25 knot ships, destroyers are most plentiful in the active fleet, have a developed retrieving technique, and show the lowest operating costs within their speed category: therefore, the 25 knot ships would presumably be destroyers.

7) There is, however, a question of using helicopters in the relatively high winds occurring a good part of the time in the Canary Islands, as discussed previously in the section on retrieving considerations, and the considerably lesser sensitivity of ships in this respect. Therefore, it might be advisable to provide duplicate coverage: helicopters to provide for possible <u>land</u> pick-up and ships to provide for pick-up in high winds.

The preferred retrieve vehicle complex is presented in Figure 51, as "Illustrative Retrieve Vehicle Complex No. 1". This is a ship-aircraft-airship-helicopter combination, derived in accordance with the above factors (but for graphical simplicity ignoring the last point of duplicate coverage in the Canaries). Data developed in the costing section were also used as a guide to minimum mission cost considerations, so that this is a preferred vehicle complex in the sense of both minimum cost and minimum number of vehicles required.

In detail, this complex consists of:

1) An HR2S helicopter at Cape Canaveral, covering the first 130 n. mi. of the launch track.

2,3) Two 25 knots operational speed ships each covering a 69 n. mi. radius within a 3 hour access time. If there is no abort in this area, the second ship redeploys to the east to cover a part of Area 7 for a second orbit landing (the second location is at the center of the dotted circle).

4) An airship 250 n. mi. west of Bermuda. If there is no abort in this area, the airship redeploys westward to cover the remainder of Area 7 for a second orbit landing. The first position is at the center of a 230 n. mi. radius, 6 hour circle; the second position is at the center of a 110 n. mi. radius, 3 hour circle.

5) An HUS helicopter at Bermuda, covering out to about 100 n. mi. from Bermuda. An H-21 would provide an interchangeable alternate.

6) An airship 250 n. mi. east of Bermuda. If there is no abort in this area, the airship redeploys to the west to cover that portion of Area 6 which lies beyond helicopter coverage for a first orbit landing. The first position is at the center of a 230 n. mi. radius, 6 hour circle; the second position is at the center of a 110 n. mi. radius, 3 hour circle.

7,8) Two 25 knot ships giving 144 n. mi. radius, 6 hours coverage for the remaining eastern end of Area 2.

9,10) One 25 knot ship in Area 3 and one in Area 4 giving 144 n. mi. radius, 6 hour coverage.

11) An HR2S helicopter at Las Palmas in the Canary Islands to cover Area 5.

12,13) Two airships on station in Area 8 for a third orbit landing.

It should be noted that this deployment is intended to meet only the retrieving requirements. Vehicle deployment for detection and search is discussed below.

There are a number of other complexes which might be considered on a minimum or non-duplicate area coverage basis, but which would result in higher mission cost. Four alternate arrangements have been selected to illustrate the type of variety possible and to indicate the effect of vehicle selection on the numbers of vehicles required. The alternate arrangements are presented as "Illustrative Retrieve Vehicle Complex No. 2" through "No. 5". Briefly, and by illustrative number, these complexes differ from the preferred arrangement:

2) Use of an HUS or H-21 helicopter instead of an HR2S at Cape Canaveral results in the need for one additional ship. Three HUS or H-21 helicopters may be used for Area 5 instead of one HR2S, but new facilities in two locations (Hierro Island and near Cabo Bojador, Africa) would be required. Three HR2S helicopters, one 25 knot ship, and one 15 knot ship (41 n. mi., 3 hour coverage) can replace two airships in Area 8.

3) One 25 knot ship plus one 15 knot ship (86 n. mi., 6 hour coverage) can replace one airship in Area 2. One HR2S helicopter plus one 25 knot ship can replace one airship in Area 8.

4) Six 15 knot ships can replace two 25 knot ships in Area 1. Four 15 knot ships can replace two 25 knot ships at the eastern end of Area 2, two vs one in Areas 3 and 4. Two 25 knot ships are shown in Area 5: these could provide the duplicate coverage discussed above. Two HR2S and one HUS or H-21 helicopter plus three 15 knot ships can replace two airships in Area 8. The HUS or H-21 helicopter might be omitted and the edge of the area left uncovered, but for consistency it has been included.

5) A large number of 15 knot ships may replace the airships, 25 knot ships and HR2S (Canary Islands).

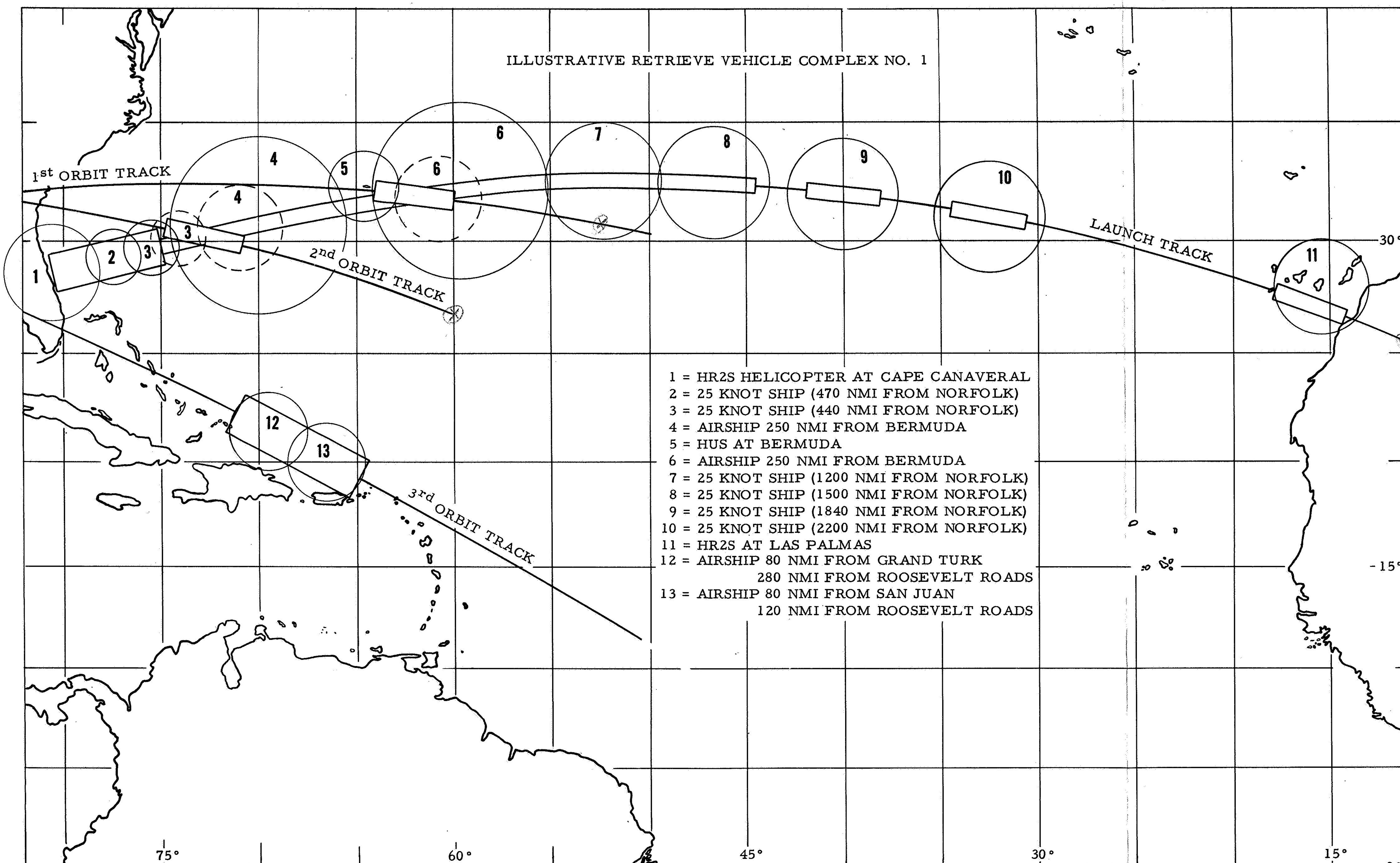

ILLUSTRATIVE RETRIEVE VEHICLE COMPLEX NO. 1
1st ORBIT TRACK
2nd ORBIT TRACK
3rd ORBIT TRACK
LAUNCH TRACK
1 = HR2S HELICOPTER AT CAPE CANAVERAL
2 = 25 KNOT SHIP (470 NMI FROM NORFOLK)
3 = 25 KNOT SHIP (440 NMI FROM NORFOLK)
4 = AIRSHIP 250 NMI FROM BERMUDA
5 = HUS AT BERMUDA
6 = AIRSHIP 250 NMI FROM BERMUDA
7 = 25 KNOT SHIP (1200 NMI FROM NORFOLK)
8 = 25 KNOT SHIP (1500 NMI FROM NORFOLK)
9 = 25 KNOT SHIP (1840 NMI FROM NORFOLK)
10 = 25 KNOT SHIP (2200 NMI FROM NORFOLK)
11 = HR2S AT LAS PALMAS
12 = AIRSHIP 80 NMI FROM GRAND TURK
280 NMI FROM ROOSEVELT ROADS
13 = AIRSHIP 80 NMI FROM SAN JUAN
120 NMI FROM ROOSEVELT ROADS
30°
15°
0°
75°
60°
45°
30°
15°

FIG. 51

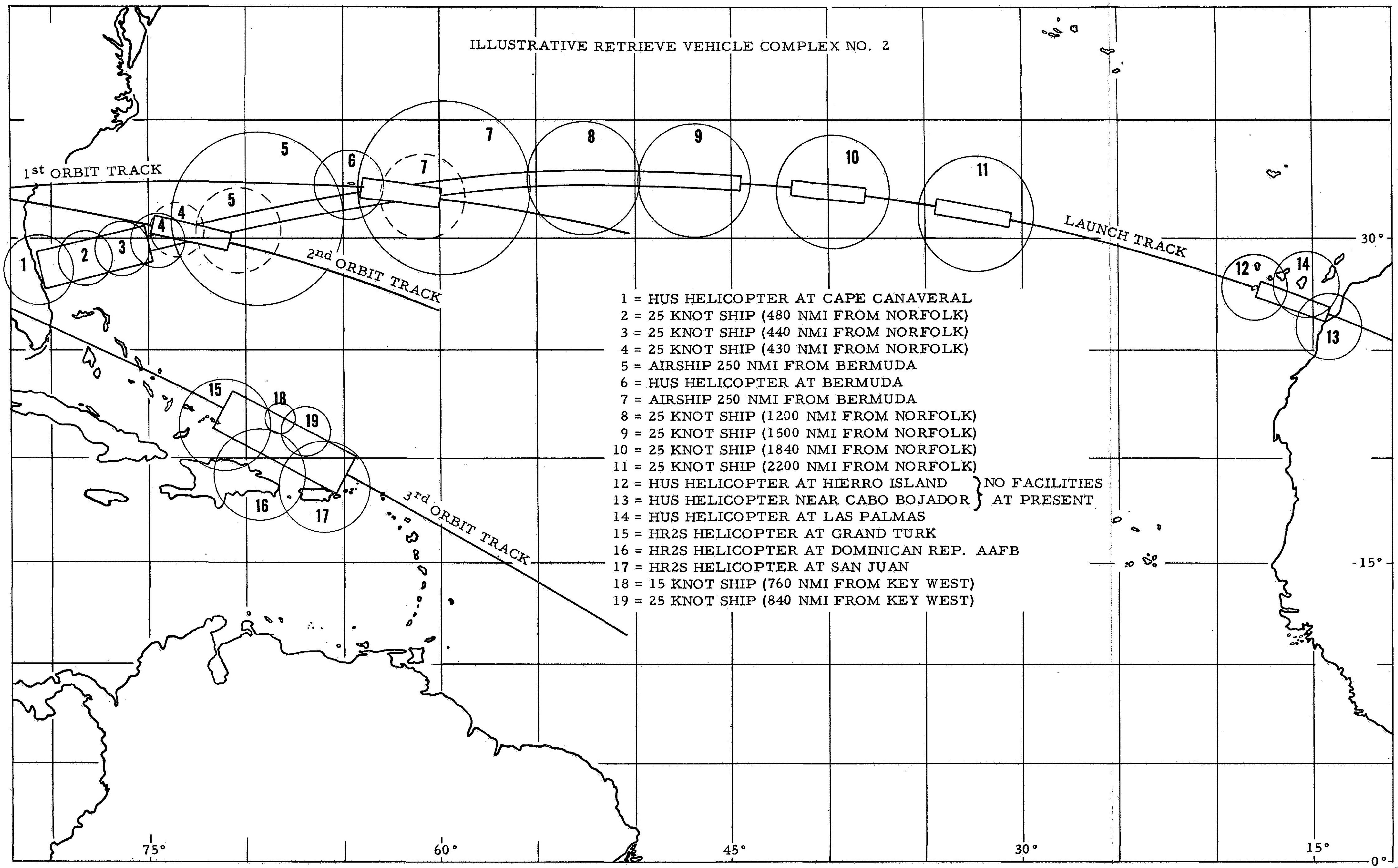

ILLUSTRATIVE RETRIEVE VEHICLE COMPLEX NO. 2
1st ORBIT TRACK
2nd ORBIT TRACK
3rd ORBIT TRACK
LAUNCH TRACK
1 = HUS HELICOPTER AT CAPE CANAVERAL
2 = 25 KNOT SHIP (480 NMI FROM NORFOLK)
3 = 25 KNOT SHIP (440 NMI FROM NORFOLK)
4 = 25 KNOT SHIP (430 NMI FROM NORFOLK)
5 = AIRSHIP 250 NMI FROM BERMUDA
6 = HUS HELICOPTER AT BERMUDA
7 = AIRSHIP 250 NMI FROM BERMUDA
8 = 25 KNOT SHIP (1200 NMI FROM NORFOLK)
9 = 25 KNOT SHIP (1500 NMI FROM NORFOLK)
10 = 25 KNOT SHIP (1840 NMI FROM NORFOLK)
11 = 25 KNOT SHIP (2200 NMI FROM NORFOLK)
12 = HUS HELICOPTER AT HIERRO ISLAND
13 = HUS HELICOPTER NEAR CABO BOJADOR
NO FACILITIES AT PRESENT
14 = HUS HELICOPTER AT LAS PALMAS
15 = HR2S HELICOPTER AT GRAND TURK
16 = HR2S HELICOPTER AT DOMINICAN REP. AAFB
17 = HR2S HELICOPTER AT SAN JUAN
18 = 15 KNOT SHIP (760 NMI FROM KEY WEST)
19 = 25 KNOT SHIP (840 NMI FROM KEY WEST)
30°
15°
0°
75°
60°
45°
30°
15°

FIG. 52

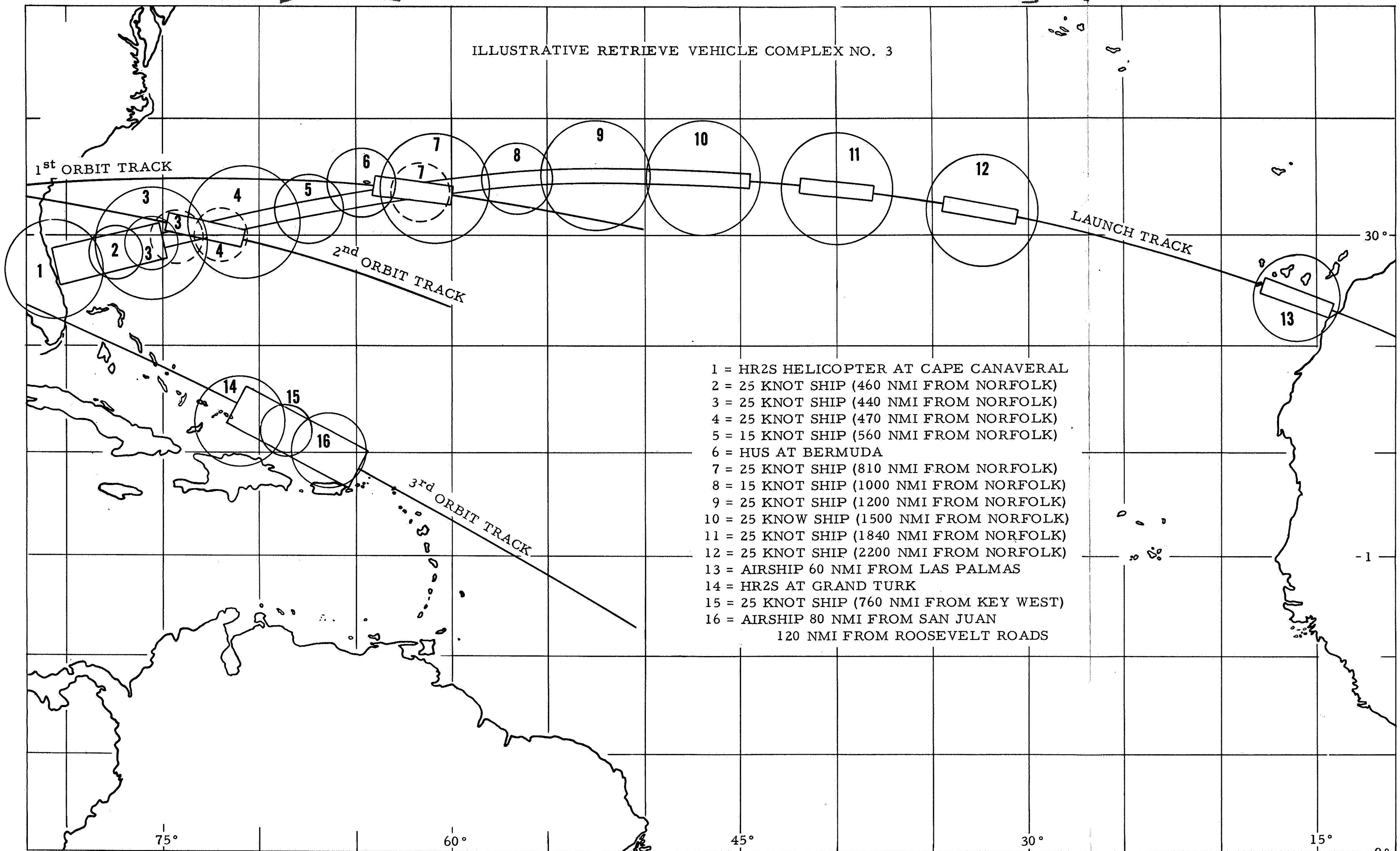

ILLUSTRATIVE RETRIEVE VEHICLE COMPLEX NO. 3
1st ORBIT TRACK
2nd ORBIT TRACK
3rd ORBIT TRACK
LAUNCH TRACK
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
30°
75°
60°
45°
30°
15°
0°
1 = HR2S HELICOPTER AT CAPE CANAVERAL
2 = 25 KNOT SHIP (460 NMI FROM NORFOLK)
3 = 25 KNOT SHIP (440 NMI FROM NORFOLK)
4 = 25 KNOT SHIP (470 NMI FROM NORFOLK)
5 = 15 KNOT SHIP (560 NMI FROM NORFOLK)
6 = HUS AT BERMUDA
7 = 25 KNOT SHIP (810 NMI FROM NORFOLK)
8 = 15 KNOT SHIP (1000 NMI FROM NORFOLK)
9 = 25 KNOT SHIP (1200 NMI FROM NORFOLK)
10 = 25 KNOW SHIP (1500 NMI FROM NORFOLK)
11 = 25 KNOT SHIP (1840 NMI FROM NORFOLK)
12 = 25 KNOT SHIP (2200 NMI FROM NORFOLK)
13 = AIRSHIP 60 NMI FROM LAS PALMAS
14 = HR2S AT GRAND TURK
15 = 25 KNOT SHIP (760 NMI FROM KEY WEST)
16 = AIRSHIP 80 NMI FROM SAN JUAN
120 NMI FROM ROOSEVELT ROADS

FIG. 53

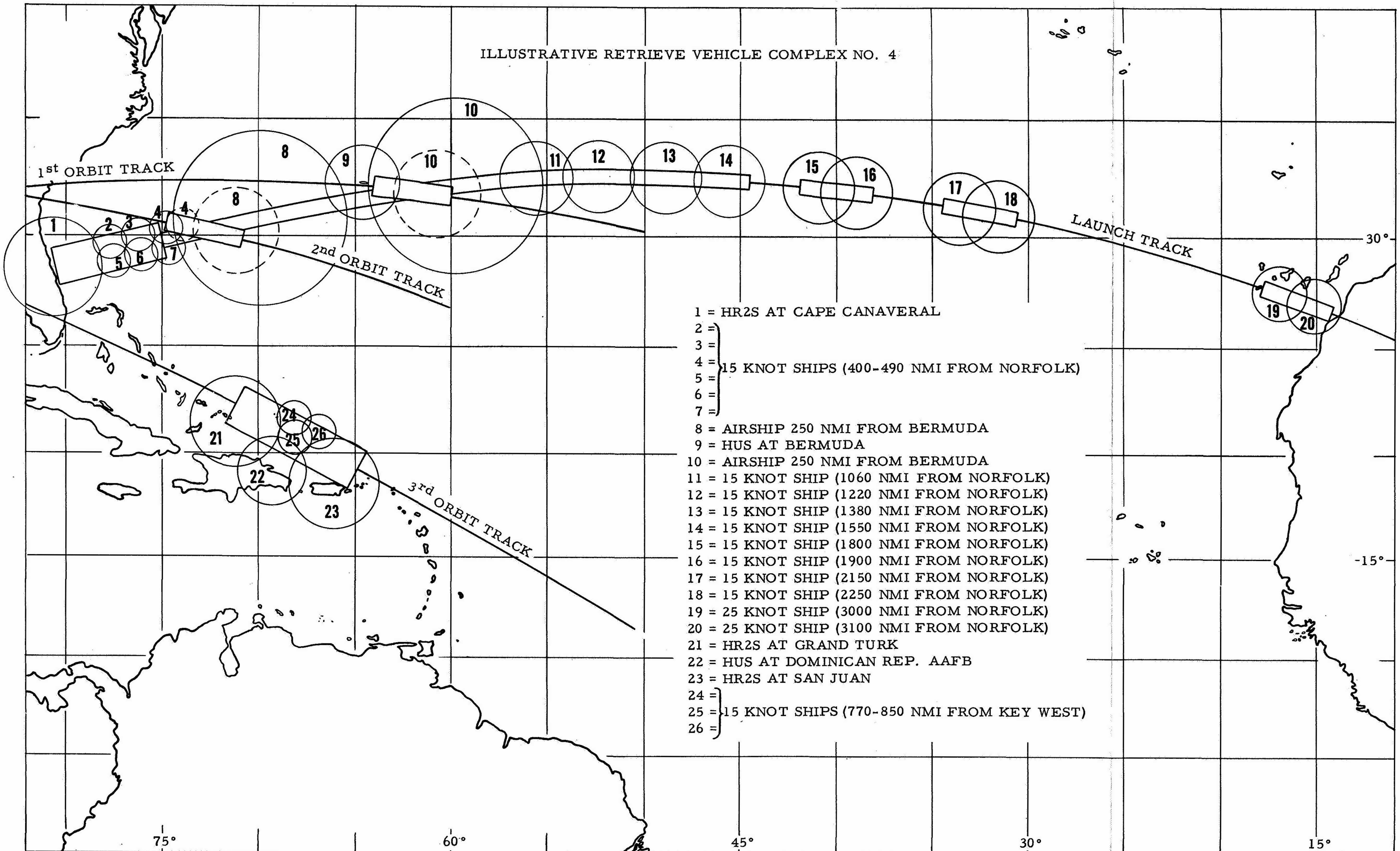

ILLUSTRATIVE RETRIEVE VEHICLE COMPLEX NO. 4
1st ORBIT TRACK
2nd ORBIT TRACK
3rd ORBIT TRACK
LAUNCH TRACK
1
2
3
4
4
5
6
7
8
8
9
10
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
30°
15°
0°
75°
60°
45°
30°
15°
1 = HR2S AT CAPE CANAVERAL
2 =
3 =
4 = 15 KNOT SHIPS (400-490 NMI FROM NORFOLK)
5 =
6 =
7 =
8 = AIRSHIP 250 NMI FROM BERMUDA
9 = HUS AT BERMUDA
10 = AIRSHIP 250 NMI FROM BERMUDA
11 = 15 KNOT SHIP (1060 NMI FROM NORFOLK)
12 = 15 KNOT SHIP (1220 NMI FROM NORFOLK)
13 = 15 KNOT SHIP (1380 NMI FROM NORFOLK)
14 = 15 KNOT SHIP (1550 NMI FROM NORFOLK)
15 = 15 KNOT SHIP (1800 NMI FROM NORFOLK)
16 = 15 KNOT SHIP (1900 NMI FROM NORFOLK)
17 = 15 KNOT SHIP (2150 NMI FROM NORFOLK)
18 = 15 KNOT SHIP (2250 NMI FROM NORFOLK)
19 = 25 KNOT SHIP (3000 NMI FROM NORFOLK)
20 = 25 KNOT SHIP (3100 NMI FROM NORFOLK)
21 = HR2S AT GRAND TURK
22 = HUS AT DOMINICAN REP. AAFB
23 = HR2S AT SAN JUAN
24 =
25 = 15 KNOT SHIPS (770-850 NMI FROM KEY WEST)
26 =

FIG. 54

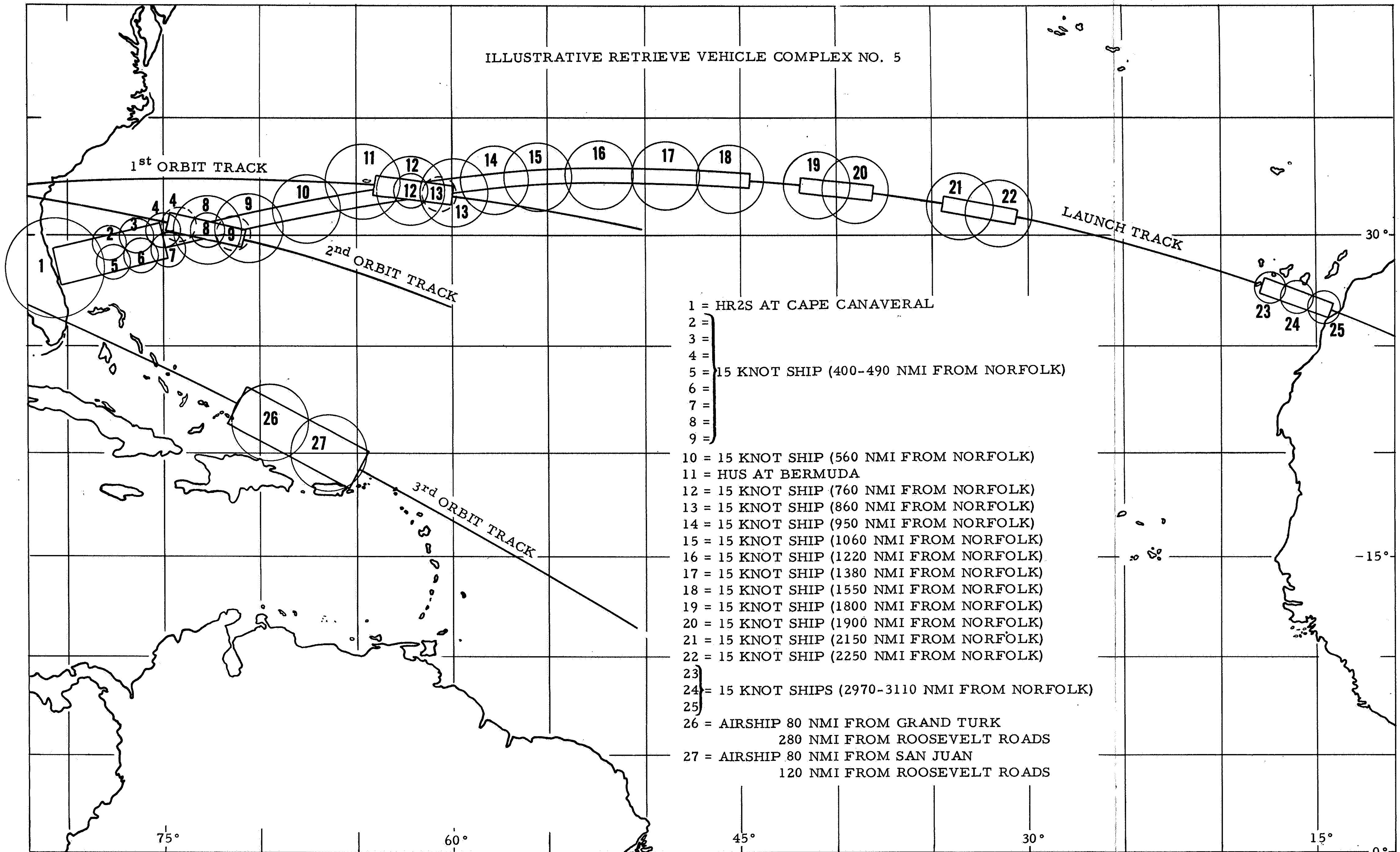

ILLUSTRATIVE RETRIEVE VEHICLE COMPLEX NO. 5
1st ORBIT TRACK
2nd ORBIT TRACK
3rd ORBIT TRACK
LAUNCH TRACK
1 = HR2S AT CAPE CANAVERAL
2 = 3 = 4 = 5 = 6 = 7 = 8 = 9 = 15 KNOT SHIP (400-490 NMI FROM NORFOLK)
10 = 15 KNOT SHIP (560 NMI FROM NORFOLK)
11 = HUS AT BERMUDA
12 = 15 KNOT SHIP (760 NMI FROM NORFOLK)
13 = 15 KNOT SHIP (860 NMI FROM NORFOLK)
14 = 15 KNOT SHIP (950 NMI FROM NORFOLK)
15 = 15 KNOT SHIP (1060 NMI FROM NORFOLK)
16 = 15 KNOT SHIP (1220 NMI FROM NORFOLK)
17 = 15 KNOT SHIP (1380 NMI FROM NORFOLK)
18 = 15 KNOT SHIP (1550 NMI FROM NORFOLK)
19 = 15 KNOT SHIP (1800 NMI FROM NORFOLK)
20 = 15 KNOT SHIP (1900 NMI FROM NORFOLK)
21 = 15 KNOT SHIP (2150 NMI FROM NORFOLK)
22 = 15 KNOT SHIP (2250 NMI FROM NORFOLK)
23 24 25 = 15 KNOT SHIPS (2970-3110 NMI FROM NORFOLK)
26 = AIRSHIP 80 NMI FROM GRAND TURK
280 NMI FROM ROOSEVELT ROADS
27 = AIRSHIP 80 NMI FROM SAN JUAN
120 NMI FROM ROOSEVELT ROADS
75°
60°
45°
30°
15°
30°
15°
0°

FIG. 55

TABLE 25

Retrieve Vehicles Required: Alternate Arrangements

Area	Helicopter HR2S	Helicopter HUS	Airship	Ship 25 Knot	Ship 15 Knot	Total Number	Illustrative Complex No.
1,2,6,7	1	1	2	4		8	1
		2	2	5		9	2
	1	1		6	2	10	3
	1	1	2		10	14	4
	1	1			16	18	5
3				1		1	1,2,3
					2	2	4,5
4				1		1	1,2,3
					2	2	4,5
5	1			2(2)		3	1
		3(1)		2(2)		5	2
			1	2(2)		3	3
				2(2)		2	4
					3(2)	3	5
8			2			2	1,5
	3			1	1	5	2
	1		1	1		3	3
	2	1			3	6	4
Total using Preferred Complex	2	1	4	8		15	1

Notes: (1) Required helicopter facilities on Hierro Island and near Cabo Bojador, Africa, not currently available.
(2) No land search capability using ships, but may be required for retrieve in relatively high winds.

The illustrative retrieve vehicle complexes presented in Figures 51 through 55 are summarized in Table 25 in terms of the numbers of each type of vehicle and also of the total number of vehicles required in each area or group of areas. The first line shown for each area represents the preferred complex, and the other lines represent the alternates. In each case, the preferred complex contains the smallest total number of vehicles and represents minimum cost. The large disadvantage in numbers required of using 15 knot ships as contrasted to 25 knot ships is quite evident. The difference is a factor of between two and three to one.

The total number of retrieve vehicles required using the preferred complex is 15: two HR2S helicopters, one HUS or H-21 helicopter, four airships, and eight 25 knot ships such as destroyers. In the event that fewer than four airships plus their necessary back-up were available, assignment of those available first to the two stations west and east of Bermuda would be recommended, because at each of those stations one airship is equivalent to two ships in coverage obtained. In other respects, the preferred complex appears quite modest in its vehicle requirements.

Among the many ship types listed earlier in Table 3, those operated in conjunction with the Atlantic Missile Range should logically be considered for inclusion in the Mercury manned capsule recovery system. None have been specifically included thus far in the discussion because of their low speed capabilities. It is suggested that the AMR ships be deployed along the third orbit track beyond Area 8 so as to give recovery coverage against a possible partial retro-impulse malfunction, for the most part within or near their usual operating region. If all twelve ships are deployed in this fashion, the 1,000 nautical miles beyond Area 8 could be covered for a 5.5 hour access time; if 60% or seven of the twelve are so deployed, a 9.2 hour access time coverage could be obtained. A further reason for this proposed use of the AMR ships is that deployed down-range of Area 8, the telemetry and other electronic equipment aboard would supplement the ground stations located along the island chain in providing very thorough tracking facilities in and around the scheduled third orbit landing area.

Detection and Search Vehicles

The deployment of detection and search aircraft depends on somewhat different principles. As developed previously in the section discussing applicable vehicles, there is a significant desirability to the use of aircraft for radar early warning coverage of an area and for performing a visual search, so that aircraft are the preferred vehicle types. Each high probability impact area must be covered for both electronic and visual detection and search either of which may govern deployment. Further selection of the extent of coverage may depend, in the final analysis, on considerations of minimum mission cost. In the discussion to follow, deployment of detection and search forces is first treated on an area coverage basis without particular regard to minimum cost, followed by consideration of minimum mission cost and its effect on the number of vehicles to be deployed.

Basically, there are two means for electronic detection, active radar seeking and passive radar or radio beacon reception, with the passive modes offering substantially longer operating ranges than offered by active seeking. The capsule is scheduled to carry C-Band and S-Band radar beacons of high enough radiated power to yield very long operating ranges, when received by matching equipment located within line of sight. Unfortunately, C- and S-Band radars are carried by only a limited number of aircraft (P5M carries C-Band, and P2V, WV-2, WF-2, and airships carry S-Band), so that the choice of aircraft must be restricted somewhat. Furthermore, under current planning, the beacons are to be available only upon inquiry by a special coded signal, and airborne equipment may not be able to send the requisite code. Therefore, the C- and S-Band beacons may not be usable for local area detection and impact prediction. In order to make them available for these purposes, their control would have to be changed, at drogue chute opening perhaps, to freerun or to respond to a simple inquiry. The change to simple inquiry would be the more desirable since range as well as bearing could then be obtained, whereas free-running would permit only bearing.

The spacing between aircraft may be selected in compliance with the extent of area coverage desired. There are three distinct "mile-stones" in the capsule descent: (1) drogue chute opening at 68,000 feet, (2) main chute opening at 10,000 feet 2.4 minutes later, and (3) impact in the sea after another 5.3 minutes. Continuous area coverage at any one of these three "mile-stones" may be desirable, with both advantages and disadvantages to each. The prime advantage of selecting continuous area coverage at one of the altitude points rather than at sea level would be increased line of sight distance to any station altitude, including the height of a land or ship radar. Provided that useful operating radar range is not exceeded, the increased line of sight distance would permit increasing the radius coverage of each aircraft and would permit the practical inclusion of land and ship radars in the coverage complex, thus reducing the number of aircraft required. Based on the assumption that atmospheric refraction is equivalent to a one-third increase in earth radius, as is commonly assumed in determining line of sight radio and radar transmission ranges, the variations in line of sight distance with station altitude and capsule altitude are:

Station Altitude	Capsule Altitude		
	68,000 ft.	10,000 ft.	Sea Level
15,000 ft.	470 n.mi.	272 n.mi.	150 n.mi.
10,000	443	246	123
1,500	367	170	47
60*	330	133	10

*represents height of land or ship radar antenna

The effect of altitude is quite evident, particularly for the land or ship radar case.

Additional points to be considered in this selection process are, for continuous coverage at:

1) 68,000 ft. - Vertical descent path is established so impact prediction would not have to be corrected for re-entry trajectory, but only for wind drift; but, there is probably only a poor chance of making a local detection by this point due to time limitations resulting from high velocity and due to heating effects which may inhibit radiation of radar beacon signals; also, contact with the capsule would be lost below 68,000 ft. until such time as a sighting vehicle could travel to within horizon distance of the surface impact point; the indicated 320 n. mi. difference in horizon distance between 68,000 ft. and sea level is equivalent to 1.5 to 2.5 hours flight for the aircraft listed in Table 4.

2) 10,000 ft. - Winds aloft below this altitude at the time of the operation would be less uncertain than above, permitting a better wind correction to impact prediction; the available time should be adequate for radar lock-on to the capsule; but, contact with the capsule would be lost until arrival of a sighting vehicle; the indicated 123 n. mi. difference in horizon distance is equivalent to between one-half and one hour flight.

3) Sea Level - With tracking to impact, winds aloft are immaterial to impact prediction; continuous coverage is for time as well as for area, since contact would not be lost; substantially longer time would be available for achieving radar lock-on.

It appears from the above that detection vehicles should be deployed to give continuous area coverage at either 10,000 ft. or sea level, in preference to 68,000 ft., for which the disadvantages of short time for tracking and long time out of contact do not seem reasonable to accept. From the stand-point of radar beacon coverage, the choice between 10,000 ft. and sea level is a matter of judgment, there being no strict technical advantage for one over the other.

Active radar detection considerations may be used as an aid to selection at this point. Use of active techniques may also permit inclusion of more than a limited number of aircraft types, because compatibility with capsule beacon equipment would not be required. As developed elsewhere in the report, chaff is released with main chute opening at 10,000 ft. to give a many-fold increase in effective radar target area, and to double or more than double useful operating radar range. It would appear to be a matter of reasonable judgment to deploy detection vehicles so as to make use of the chaff. Useful radar ranges against chaff have been given as about 120 n. mi. for the APS-20 (P2V, WV-2, WF-2, and airships), on the average about the same for radars carried by destroyers, slightly less for the Mod. II radar (AMR ground stations, Canary Islands), and 144 n. mi. for the FPS-16 (Cape Canaveral, Grand Bahama, San Salvador, and Antigua); these values provide the radar range limits to radius coverage of each vehicle or ground station.

It is also necessary to consider the horizon limit. Chaff is to be released at 10,000 ft., controlled by a pressure sensing device. Variations in weather conditions may lead to variations of almost 1,000 ft. in the altitude at which a

given pressure occurs. Including a like amount to allow for control tolerance and descent of chaff during the time necessary for obtaining a radar lock-on, it is assumed that the chaff should be above the observer's horizon until it has descended to 8,000 ft. altitude. The corresponding line of sight distance is about 120 n. mi. for a radar antenna located at 60 ft. height; this is equivalent to the useful ranges of the destroyer and Mod. II radars and less than that of the FPS-16, and will now replace the last.

It thus appears that a 120 n. mi. radius coverage may be assigned to land stations and ships, and to detection aircraft equipped with the S-Band APS-20 radar (P2V, WV-2, WF-2, and airships), based on active detection of chaff, with the possibility of S-Band radar beacon detection for additional information. For the P5M, which carries C-Band radar, a 100 n. mi. radius coverage may be used, again with a possibility of beacon detection. Other aircraft, such as the S2F and SA16 for example, equipped with X-Band radar, would be limited to about 35 n. mi. radius coverage, and would not have beacon reception capability in either C- or S-Band. At the operating ranges to be assumed, aircraft station altitudes would not be critical, since only a sea level observer would be horizon limited in coverage.

The criterion for deployment of search aircraft is that any point within the coverage area may be reached and an impact area uncertainty then searched with a high probability of detection within a reasonable total elapsed time. The limiting coverage per search aircraft would be that for which the total of initial time lost for communications, etc., transit time to a point on the perimeter of the coverage circle, and search time would be enough less than the desired access time to permit some advance notice of exact position to a retrieve vehicle prior to its arrival in the general area of impact.

Figure 56 presents an "Illustrative Detection and Search Complex" based on providing continuous area coverage for chaff detection, using the radar capabilities of the retrieve vehicles in the preferred complex, (Figure 51), and land stations along the track. Each ship, airship, and land station has been considered to give 120 n. mi. radius coverage as noted above. Gaps existing between adjacent land or retrieve vehicle radars have been filled by aircraft, selection being on the basis of both airplane performance and installed radar equipment. In each instance, the aircraft specified represents the minimum satisfactory level of time on station vs. station radius performance or the minimum radar range capability. A given station could also be covered by any other aircraft having greater time-radius performance or greater radar capability (e.g., C- or S-Band vs. X-Band). Thus, S2F's have been selected for search near Cape Canaveral, in the Canary Islands area, and in the scheduled third orbit landing area; each S2F can remain on the ground until impact, fly to the predicted impact point, search the area of uncertainty, and locate the capsule well in advance of arrival of a retrieve vehicle, at points corresponding to the longest access time within the assigned coverage radius. Moving up in capability, SA-16's (UF's) are assigned to stations requiring no more than X-Band radar and falling within the performance capability of either the A or B model of the airplane. East of the airship located east of Bermuda, the required

radar range is beyond X-Band equipment but within C-Band capability, and the P5M is specified. There is no aircraft station requiring S-Band radar range capability for chaff detection.

Figure 56 includes consideration of detection in the event of over-shoot or under-shoot of the landing areas. The radius coverage to drogue chute opening at 68,000 ft. altitude is shown for each land radar station, a 330 n. mile radius; the land radars can trigger the capsule beacons and obtain range and direction information. The over-shoot coverages gained, beyond the down-range ends of the areas, are: 240 n.mi. beyond Area 5, 80 n.mi. beyond Area 6, 490 n.mi. beyond Area 7, and 530 n.mi. beyond Area 8. Including aircraft station 5 and the next ship eastward, 380 n. mi. beyond Area 6, is covered; additional over-shoot coverage for Area 6 can be provided by the Mid-Atlantic Ship, telemetry equipped, about 1050 n.mi. beyond.

Over-shoot coverage of Area 8 can be gained through use of the Antigua and St. Lucia ground stations, plus the equipment installed on the AMR ships. A possible deployment of seven of the AMR ships is shown in Figure 56 to illustrate this suggestion, six of the FS's or C1-M-AVI's with their telemetry plus the DAMP ship with its high capability radar being disposed over a roughly 1,000 n.mi. distance down-range; this is in line with the earlier suggestion for their use for retrieve.

Just as each of several stations and ships can provide over-shoot coverage, they can also provide under-shoot coverage. Cape Canaveral radar can cover Area 7, Bermuda cover Area 6, Las Palmas Area 5, and Cape Canaveral plus the island chain along the AMR can cover Area 8.

Therefore, there is quite complete coverage of all high probability areas for detection both in and around each area. Within areas, active radar detection of chaff is the criterion; for over-shoot or under-shoot, detection is possible after the vertical descent is established, using either active (available because of very high power in the land-based radars) or passive (beacon reception) means.

For each detection aircraft station, a second (dotted) circle is shown in Figure 56 to indicate coverage for search. Additional dotted search circles are shown about Patrick AFB for the Cape Canaveral end of Area 1, about a point midway between Areas 3 and 4, about Las Palmas for Area 5, and about the Dominican Republic AAFB for Area 8. A dotted circle is also shown centered at Artigua to indicate search aircraft coverage for over-shoot of Area 8. In the event that such over-shoot coverage were to be provided, both Area 8 and the over-shoot could be covered by one P2V or WV-2 (but not a slower aircraft) stationed at San Juan, Puerto Rico; this would be more economical in both vehicle number and mission cost than providing the separate coverage illustrated. Of the search-only aircraft, only the one between Areas 3 and 4 would have to be in the air on station in advance of launch and capsule arrival. All search aircraft deployed as in Figure 56 could fulfill the criterion noted above for search aircraft.

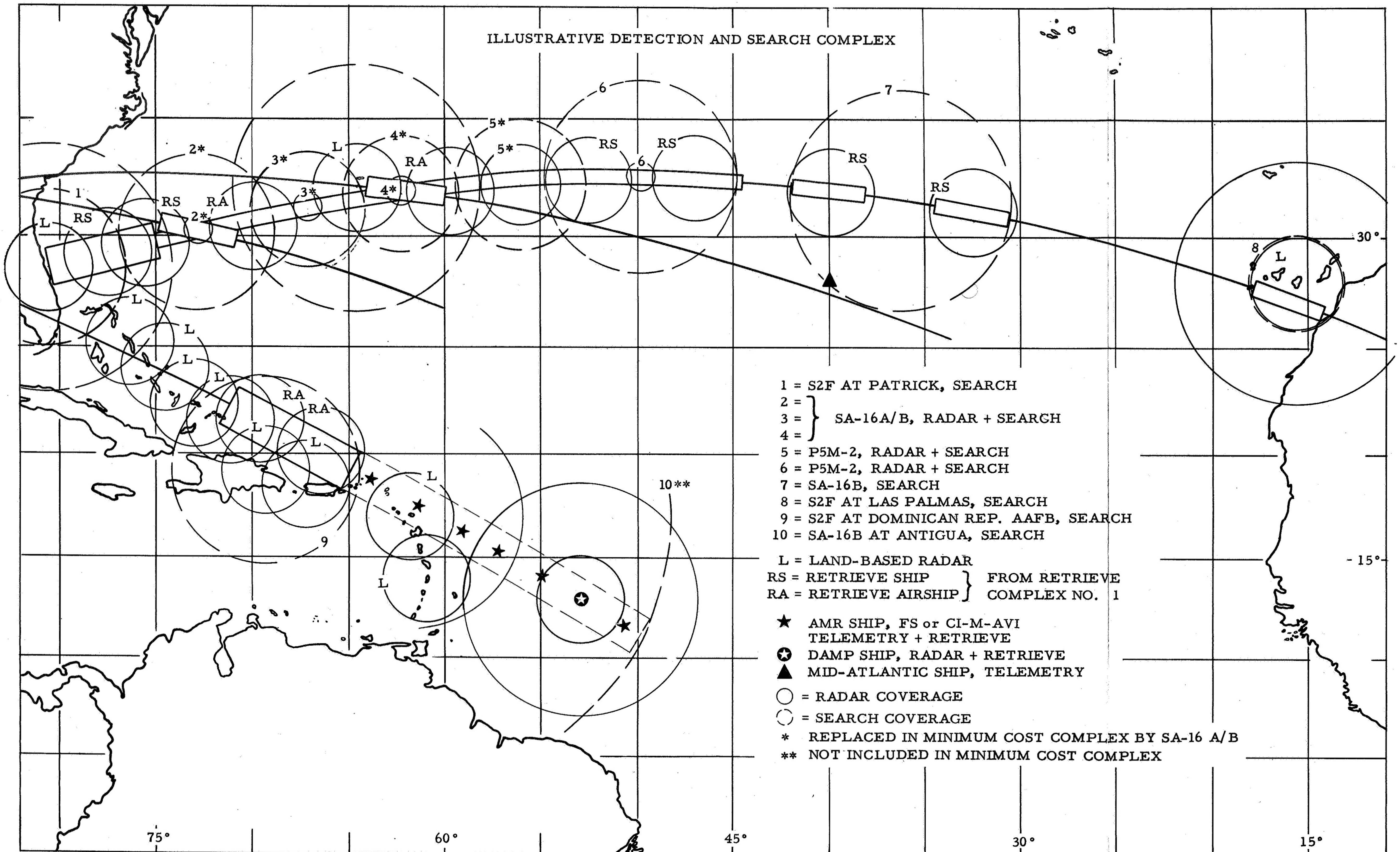

ILLUSTRATIVE DETECTION AND SEARCH COMPLEX
1 = S2F AT PATRICK, SEARCH
2 =
3 = SA-16A/B, RADAR + SEARCH
4 =
5 = P5M-2, RADAR + SEARCH
6 = P5M-2, RADAR + SEARCH
7 = SA-16B, SEARCH
8 = S2F AT LAS PALMAS, SEARCH
9 = S2F AT DOMINICAN REP. AAFB, SEARCH
10 = SA-16B AT ANTIGUA, SEARCH
L = LAND-BASED RADAR
RS = RETRIEVE SHIP
RA = RETRIEVE AIRSHIP
FROM RETRIEVE COMPLEX NO. 1
AMR SHIP, FS or CI-M-AVI TELEMETRY + RETRIEVE
DAMP SHIP, RADAR + RETRIEVE
MID-ATLANTIC SHIP, TELEMETRY
= RADAR COVERAGE
= SEARCH COVERAGE
* REPLACED IN MINIMUM COST COMPLEX BY SA-16 A/B
** NOT INCLUDED IN MINIMUM COST COMPLEX
75°
60°
45°
30°
15°
0°
15°
30°
10**

FIG. 56

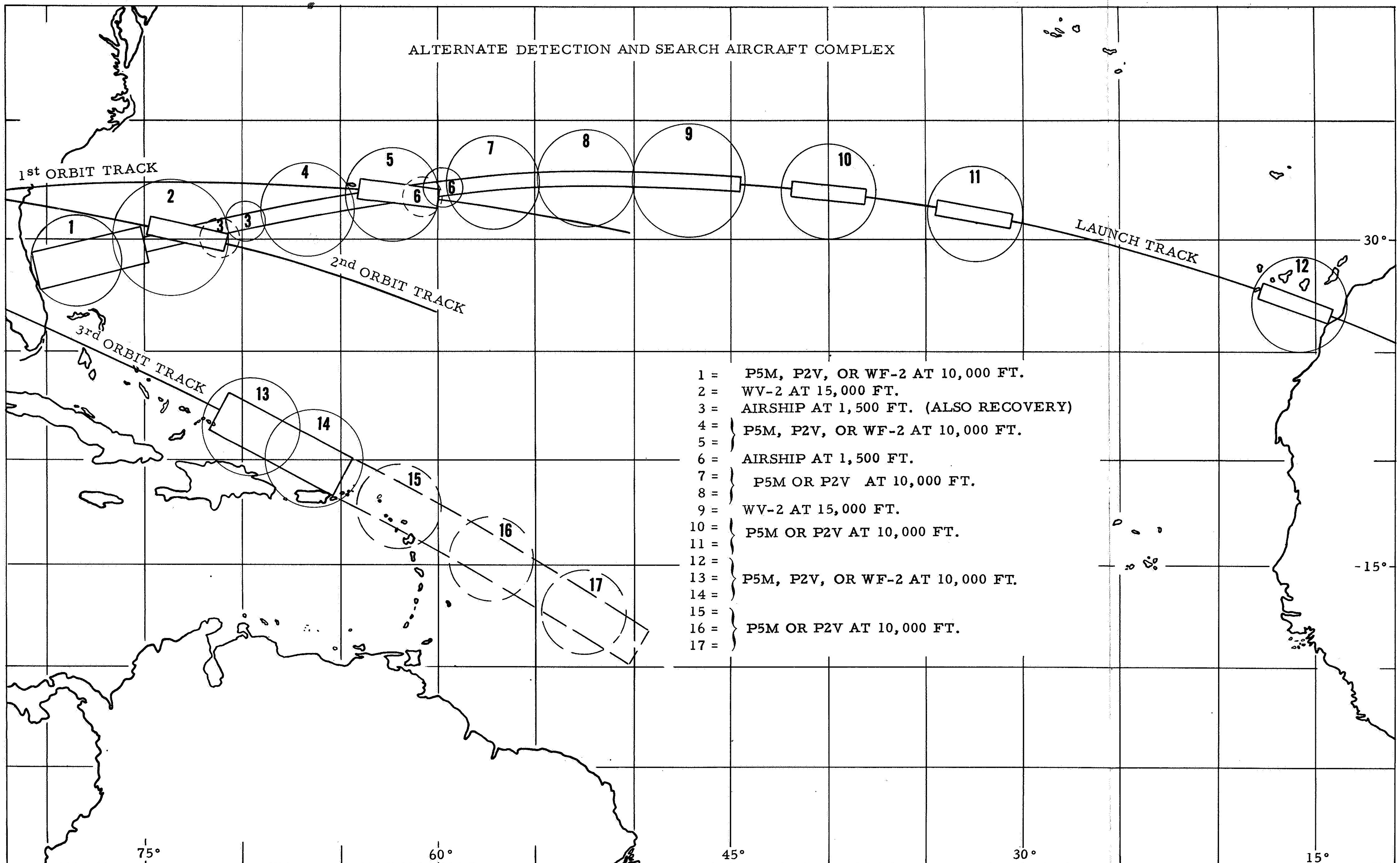

ALTERNATE DETECTION AND SEARCH AIRCRAFT COMPLEX
1st ORBIT TRACK
2nd ORBIT TRACK
3rd ORBIT TRACK
LAUNCH TRACK
1 = P5M, P2V, OR WF-2 AT 10,000 FT.
2 = WV-2 AT 15,000 FT.
3 = AIRSHIP AT 1,500 FT. (ALSO RECOVERY)
4 = 5 = P5M, P2V, OR WF-2 AT 10,000 FT.
6 = AIRSHIP AT 1,500 FT.
7 = 8 = P5M OR P2V AT 10,000 FT.
9 = WV-2 AT 15,000 FT.
10 = 11 = P5M OR P2V AT 10,000 FT.
12 = 13 = 14 = P5M, P2V, OR WF-2 AT 10,000 FT.
15 = 16 = 17 = P5M OR P2V AT 10,000 FT.
30°
15°
0°
75°
60°
45°
30°
15°

FIG. 57

The resulting aircraft deployment is as follows:

1) S2F's at Patrick AFB (station 1), Las Palmas in the Canaries (station 8), and Dominican Republic AAFB (station 9). These aircraft are for search only, so that their short-range X-Band radar is adequate. The SA-16/UF aircraft type would provide the next step up in airplane time on station vs. station radius performance capability.

2) SA-16/UF's at station numbers 2,3,4,7 and 10; stations 2 through 4 require only short radar range, within X-Band capability, and stations 7 through 10 are for search only. The next up in airplane performance capability would be the P5M-2, which also offers the next up in radar capability, C-Band.

3) P5M-2's are shown for station 5 in consideration of radar requirement and for station 6 because of airplane performance required. In each case, the P2V would provide the next step up in capability.

In order to illustrate further the ways in which aircraft might be deployed for detection and search, an "Alternate Detection and Search Aircraft Complex" is presented in Figure 57 . This complex was derived assuming continuous radar beacon reception coverage of the entire surface in each area, with the exception of Area 8 over-shoot for which the area coverage is somewhat less than continuous. Because of capsule equipment, only the P5M with C-Band radar and the P2V, WV-2, WF-2, and airships with S-Band radar are included from the list of aircraft in Table 4 . However, a change in capsule beacon control from special coded signal to simple inquiry would be required so as to permit reception by the aircraft for range as well as bearing information.

The unpressurized P5M, P2V, and WF-2 are assigned station at 10,000 ft. altitude, but no higher in consideration of crew comfort and operational efficiency; coverage of the sea surface is limited by the horizon to about 120 n.mi. radius about the station. The pressurized WV-2 is assumed on station at 15,000 ft., close to its capabilities at engine power settings giving economical fuel consumption; the horizon limit to sea surface coverage is about 150 n.mi. In each case, the assumed station altitude is well below service ceiling, which occurs generally between 20,000 ft. and 30,000 ft. Airships are assumed on station at 1,500 ft. altitude, representative of a reasonable operating height, giving about 45 n.mi. radius coverage of the sea surface. The three coverage radii are very substantially less than the usable operating beacon reception range. Ships and land radar stations are not included in Figure 57 because their possible coverage of the sea surface would be almost negligible.

It is interesting to note that this alternate arrangement would require 15 aircraft in contrast to the 10 required by the previous, first illustration, including separate coverage of the over-shoot of Area 8. The coverage is more extensive area-wise and time-wise, but the choice of aircraft types is restrictive because of installed equipments. The number of aircraft required cannot be reduced noticeably except by decreasing the area coverage. As shown by

Figure 58 , the number of aircraft required cannot be reduced very much by use of higher altitudes, since the greatest benefit of altitude is obtained between sea level and 10,000 ft. to 15,000 ft.; Figure 58 was obtained through a suitable combining of Figures 7 and 48 .

A minimum cost detection and search complex of forces may also be derived consistent with the desired access times and with the requirements for a high probability of successful recovery. Reduction in numbers of vehicles to this end would entail acceptance of gaps in local detection coverage and making up for the degradation in detection by increased aircraft transit plus search time. The larger radii covered by the aircraft would mean longer transit time from station to predicted impact location; the lack of a local detection and impact prediction would result in a larger area of uncertainty associated with impact prediction by a remote land-based radar station. The limiting radius coverage would be approached as the transit plus search time became not enough less than the desired access time to permit sufficient advance time for re-directing an approaching retrieve vehicle. If the advance time of capsule location by a search aircraft prior to arrival of a retrieve vehicle is too small, a large change in direction of travel may be required, resulting in a significant reduction in effective radius coverage per retrieve vehicle and a consequent increase in numbers required. Determination of the level of effort for minimum cost may be made following the procedure discussed in the costing section.

It is estimated that one search aircraft could cover approximately 700 to 800 n. mi. of track length within a 6-hour access time, consistent with a practical requirement for advance time and consistent with the retrieve vehicle coverages shown in Figure 51 for the preferred retrieve complex. Applying the 700 to 800 n.mi. track length coverage to the illustrative detection and search complex, Figure 56 ,would permit deleting aircraft station numbers 2 through 5 and replacing them by one aircraft on the ground at Bermuda. Because of the distances separating the several recovery areas, no further changes would be possible.

The net change is a reduction by three in the number of aircraft required and a reduction by four in the number of aircraft in the air on station, in favor of one added on the ground. The cost savings would be the operating costs of four aircraft in the air on station plus the staging costs, if any, of the three aircraft deleted. The savings inherent in having an aircraft available on the ground rather than in the air on station would be significant. It should be borne in mind that the resulting minimum cost system does not represent any lowering of the probability of success in the recovery operation, only a reduction in continuity of area coverage for local detection and impact prediction.

Aircraft carriers have not been included in any of the illustrative vehicle complexes because their possible contribution would not be in keeping with either their operating capabilities or their operating costs. A carrier plus four S2F aircraft based on the carrier could cover the eastern end of Area 2 between 45° and 55° west latitude, covered by two ships and one aircraft in

NUMBER OF DETECTION AND SEARCH AIRCRAFT REQUIRED vs STATION ALTITUDE

AREA 2 (40 × 1600 N.Mi)

BASED ON CONTINUOUS LINE OF SIGHT COVERAGE OF ENTIRE AREA

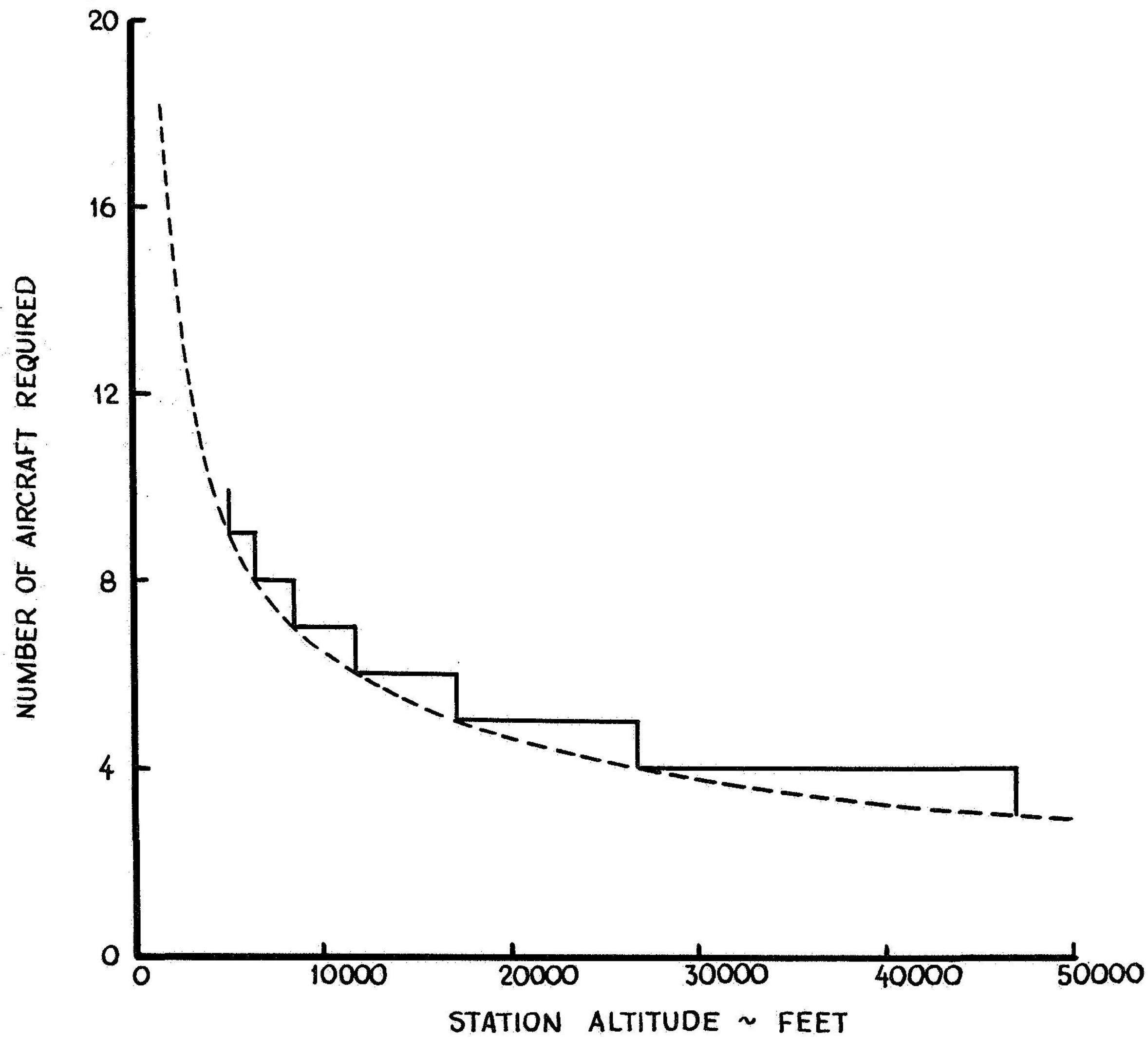


FIG. 58

Figure 56 , for chaff detection and for search, but the aircraft would require relief in case of a firing hold; the two more remote S2F's would require relief irrespective of holds because of the long access times prevailing in Area 2. The carrier could also act as a base for a retrieve helicopter, thus doing double duty. With a 6 hour access time specified, and with an HR2S capable of a 130 n.mi. radius of action with a 2 hour access time, a 25 knot operational speed carrier could steam 100 n.mi. in the first four hours for a total radius coverage of 230 n.mi. This coverage could take the place of retrieve station 7 and most of 8 in Figure 51 . The net would be: 1-aircraft carrier, 4-S2F aircraft plus relief for each, and 1-HR2S.

This represents only a small part of the aircraft basing capability of a carrier, and would result in a substantially higher operating cost than the one larger aircraft and two smaller ships included in Figures 51 and 56 , which provide the same coverage. The same negative result could also be obtained in other portions of the several areas to be covered, so that aircraft carriers have been omitted as not belonging strictly in the form of minimum system derived herein.

A somewhat similar retrieve system combining LSD's and HUS helicopters might also be used. Taking the HUS capability as 3 hours access time at 100 n.mi. radius or 200 n.mi. range, in accordance with previous discussion, and assuming use of a Thomaston class LSD with a 15 knot operational speed, the radius coverage would be 45 n.mi. for the first three hours travel by the LSD plus 122 n.mi. outbound distance for the HUS, or 167 n.mi. total. The balancing return leg of the operation is 90 n.mi. covered by the LSD in 6 hours, plus the remaining 78 n.mi. of the HUS range. Since the total is of the same order of magnitude as the 144 n.mi., 6-hour coverage of a 25 knot operational speed ship, the two systems would be approximately equivalent in the number of retrieve vehicles required. However, the operating cost of an LSD-HUS combination would be higher than that of a destroyer, as may be seen by referring to the costing section of this report.

In order to provide emergency coverage against sinking of the capsule, ships such as sub rescue vessels might be deployed in shallow water areas. These areas would be close to Bermuda and in the third orbit landing area, Area 8 capsule sinking in deep water areas would not be coverable in the suggested manner.

STAGING AND RE-CYLCING CONSIDERATIONS

Putting the Mercury manned capsule recovery program into operation will require a substantial amount of coordination. The high probability impact areas range from Cape Canaveral east to the Canary Islands over 3,000 nautical miles distant and southeast to the vicinity of Puerto Rico 1,000 nautical miles distant. Vehicles which may be involved in the operation may range all the way from 15 knots (or lower) operational speed to over 200 knots cruise speed for aircraft. Some vehicles have the operating range capability of proceeding unaided to their assigned areas, others may have to be delivered in advance. In certain cases, there may be no facilities currently available. In addition, re-cycling of some vehicles may be necessary so as to provide the requisite coverage of certain stations. Thus, there are many facets to controlling the operation. This section of the report is intended to outline the necessary staging and re-cycling problems and to serve as a guide to the overall mission planning.

Staging

In order to establish a frame of reference, the following assumptions are made:

1. Ships are staged from Norfolk, Virginia, for deployment in Areas 1 through 7 and from Key West, Florida, for Area 8.

2. Aircraft are staged from Brunswick, Maine, via Argentia, for deployment from the Azores and Via Argentia and the Azores for deployment in the Canary Islands; from Norfolk, Virginia, for deployment from Bermüda, excepting SA-16/UF's and P5M's which are assumed ordinarily based at Bermuda; and from Miami, Florida, for deployment in Area 8, and Area 8 over-shoot, with Guantanamo Bay used as an intermediate stop between Miami and Dominican Republic AAFB, and Antigua. The three staging bases are representative of northeastern, central eastern, and southeastern United States.

3. Aircraft operating from Patrick AFB and helicopters from Cape Canaveral do not require staging.

4. Airships are staged from Lakehurst, New Jersey, for deployment from Bermuda; and from Glynco, Georgia, via Guantanamo Bay for deployment in Area 8 from Roosevelt Roads.

5. Aircraft having insufficient range capabilities for travel to the assigned deployment bases are delivered in advance.

6. A minimum two-hour ground time for refueling is assumed for staging stops up to a limit of eight hours flight time for two successive route segments combined; for longer flight times, an over-night stop is assumed, to allow for crew rest.

7. Aircraft are assumed to arrive at the base for operation one day in advance to allow for refueling, line maintenance, crew rest, and last minute coordination.

8. Ships are assumed to arrive on station somewhat in advance to allow confirmation of location and weather reporting.

The staging distances appropriate to the selected mode of operation are:

Brunswick to Argentia, Newfoundland	700 n.mi.
Argentia to Lajes, Azores	1300 "
Lajes to Las Palmas, Canary Islands	860 "
Norfolk to Bermuda	640 "
Lakehurst to Bermuda	640 "
Miami to Guantanamo Bay	460 "
Glynco to Guantanamo Bay	760 "
Guantanamo to Dominican Republic AAFB	330 "
Guantanamo to Roosevelt Roads	500 "
Guantanamo to Antigua AAFB	760 "

Tables 26 and 27 present staging data for detection and search aircraft and for retrieve vehicles, respectively, for the preferred illustrative complexes discussed earlier. Each vehicle is identified by the number of its station as used in the appropriate illustration, Figure 51 or 56 ,base to be used for the recovery operation, staging base and distance, enroute speed, staging time, and departure day. Both minimum time on station vs. station radius capability or radar capability aircraft and next alternate are shown.

The staging departure days for detection and search aircraft range from 1½ to 4 days in advance for aircraft which are able to proceed unaided; if an S2F is to be used in the Canary Islands Area 5, it must be delivered in advance. The staging departure days for retrieve vehicles range from 1½ to 6½ days in advance, except for the helicopters based at Bermuda and at Las Palmas in the Canary Islands, these requiring delivery in advance. An enroute speed of 15 knots was assumed for the 25 knots operational speed ships to represent a reasonable fuel economy cruising condition.

Table 28 presents a vehicle staging time table, resulting from a combination and re-arrangement of Tables 26 and 27 . As may be seen, the staging coordination required must regulate the departure of aircraft and ships at one half to one day intervals from five different areas.

A similar staging illustration could be set up for each of the alternate vehicle complexes discussed earlier, and would show detail differences in departure interval, departure area, and earliest departure day. The earliest departure day, among all the selected complexes, would be for retrieve vehicle No. 25 in Figure 55 . Assuming a 10 knot enroute speed for this 15 knot operational speed ship, departure would be at -13 days for an arrival at -1 hour. A 25 knot ship in the same location, Figure 54 , would depart at -9 days for an arrival at -8

TABLE 26

STAGING OF AIRCRAFT FOR DETECTION AND SEARCH Ref: Fig. 56 Table 29

Station Number	Vehicle	Base For Operation	Staging Base	Distance N. Mi.	Enroute Speed-Knots	Staging Time Hours	Staging Time Days	Departure Day(1)
1	S2F	Patrick	No staging necessary					
	SA-16A/B	Patrick	No staging necessary					
2	SA-16A/B	Patrick	No staging necessary					
	P5M-2	Patrick	No staging necessary					
RA	Airship	Bermuda	Lakehurst	640	40	16.0		-2
3	SA-16A/B	Bermuda	No staging necessary					
	P5M-2	Bermuda	No staging necessary					
4	SA-16A/B	Bermuda	No staging necessary					
	P5M-2	Bermuda	No staging necessary					
RA	Airship	Bermuda	Lakehurst	640	40	16.0		-2
5	P5M-2	Bermuda	No staging necessary					
	P2V-5/7	Bermuda	Norfolk	640	170	3.8		-1½
6	P5M	Bermuda	No staging necessary					
	P2V-5/7	Bermuda	Norfolk	640	170	3.8		-1½
	WV-2	Bermuda	Norfolk	640	215	3.0		-1½
7	SA-16B	Azores	Brunswick	2,030	135	15.0(2)	2(3)	-3
	P5M-2	Azores	Brunswick	2,030	150	13.5(2)	2(3)	-3
	P2V-5/7	Azores	Brunswick	2,030	170	12.0(2)	2(3)	-3
	WV-2	Azores	Brunswick	2,030	215	9.4(2)	2(3)	-3
8	S2F	Canary	Must be delivered in advance					
	SA-16A/B	Canary	Brunswick	2,890	135	21.4(2)	3(4)	-4
9	S2F	Dom. Rep.	Miami	790	130	8.1(5)		-1½
	SA-16A/B	Dom. Rep.	Miami	790	135	7.9(5)		-1½
10	SA-16B	Antigua	Miami	1,220	135	9.0(2)	2(3)	-3
	P5M-2	Antigua	Miami	1,220	150	10.0(5)		-1½
	P2V-5/7	Antigua	Miami	1,220	170	9.2(5)		-1½
	WV-2	Antigua	Miami	1,220	215	7.7(5)		-1½

NOTES:
1. Launch time taken as zero time reference.
2. Flight time only.
3. Includes one over-night stop.
4. Includes two over-night stops.
5. Includes one two-hour stop.

TABLE 27

STAGING OF RETRIEVE VEHICLES - PREFERRED COMPLEX

Reference: Figure 51

Station Number	Vehicle	Base For Operation	Staging Base	Distance N. Mi.	Enroute Speed-Knots	Staging Time Hours	Staging Time Days	Departure Day (1)
1	HR2S	Canaveral	No Staging Necessary					
2	25K Ship	—	Norfolk	470	15		1.3	-1½
3	25K Ship	—	Norfolk	440	15		1.2	-1½
4, 6	Airship(2)	Bermuda	Lakehurst	640	40	16		-2
5	HUS	Bermuda	Must be delivered in advance					
7	25K Ship	—	Norfolk	1,200	15		3.3	-3½
8	25K Ship	—	Norfolk	1,500	15		4.2	-4½
9	25K Ship	—	Norfolk	1,840	15		5.1	-5½
10	25K Ship	—	Norfolk	2,200	15		6.1	-6½
11	HR2S	Canary	Must be delivered in advance					
12, 13	Airship	Roosevelt R.	Glynco	1,260	40	32(3)	2.5(4)	-3½

NOTES:
1. Launch time taken as zero time reference.
2. Also part of detection and search complex.
3. Flight time only.
4. Includes one over-night stop.

Table 28

Vehicle Staging Time-Table

Departure Day	From	Detection	Retrieve	Enroute Day	Departure From	Arrival Time
$-6\frac{1}{2}$	Norfolk		10			-10 hours
$-5\frac{1}{2}$	Norfolk		9			-10 hours
$-4\frac{1}{2}$	Norfolk		8			- 7 hours
-4	Brunswick	$8^{(1)}$		-3	Argentia	
				-2	Azores	- 1 day
$-3\frac{1}{2}$	Norfolk		7			- 5 hours
$-3\frac{1}{2}$	Glynco		12,13	$-2\frac{1}{2}$	Guantanamo	- 1 day
-3	Brunswick	7		-2	Argentia	- 1 day
-3	Miami	$10^{(2)(3)}$		-2	Guantanamo	- 1 day
-2	Lakehurst	RA	4,6			- 1 day
$-1\frac{1}{2}$	Norfolk	$5,6^{(4)}$				- 1 day
$-1\frac{1}{2}$	Norfolk		2			- 5 hours
$-1\frac{1}{2}$	Norfolk		3			- 7 hours
$-1\frac{1}{2}$	Miami	$9,10^{(5)}$		-1+	Guantanamo	- 1 day
No staging		1,2,3,4, $5^{(3)},6^{(3)}$	1			
Advance delivery		$8^{(3)}$	5,11			

Notes:
1. Alternate, next to lowest time-radius capability.
2. Coverage for overshoot of Area 8.
3. Lowest usable time-radius capability aircraft choice.
4. Applies to P2V or WV-2.
5. Except for lowest capability aircraft at -3 days.

hours; the advantage over the slower ship would be 4 days each way, or 8 fewer days required for the complete operation. There would, therefore, be a total commitment time advantage to use of faster ships, as well as the previously discussed advantage in numbers of ships required.

Within the over-all mission staging problem, there is the smaller problem of staging aircraft to cover the required stations and to perform the detection and search tasks. It is necessary to consider also the question of re-cycling since relief might be required so as to cover some stations adequately.

Recycling

Table 29 presents aircraft cycle data corresponding to Figure 56, showing data for both the minimum capability aircraft and the next as well. For stations located substantial distances from base, longer time-radius performance aircraft are also included, since they might be considered more suitable operationally, in such areas. The maximum hold tolerable using one aircraft without relief is shown for each case; the shortest hold noted in this table is two hours, for a minimum capability aircraft. Otherwise, it is apparent that quite substantial firing holds could be tolerated without recycling, especially since short time in the air capability aircraft types can be assigned to stations for which take-off may be delayed until after impact. Therefore, since it is unlikely that there will be a hold for more than two hours without postponement for a day, all of the aircraft specified appear sufficient to cover even the most marginal stations. If there is to be a long hold, on the other hand, the entire aircraft complex including the airships could be recycled in 12.5 hours (6:15 hours travel each way for the first airship) plus turn-around time; for the fixed wing types along, recycling could be accomplished in 11.6 hours (5:47 hours travel each way) plus ground turn-around. Thus, in the event of a 24 hour delay, there should be no difficulty recycling the entire airborne vehicle complex.

With respect to a minimum cost complex, it is noted in Table 29 that aircraft numbers 2 through 5 would be deleted in favor of one aircraft on the ground at Bermuda. Inasmuch as the aircraft specified for those stations are assumed not to require staging, with the exception of the P2V alternate for number 5, there would be no change in staging for the minimum cost complex vs. the more comprehensive coverage. Recycling, on the other hand, would be simpler in that the number of aircraft recycled would be four less.

Just as certain aircraft would require relief so as to cover their stations adequately, some of the ships involved in the recovery effort would require re-supply, or logistics support. For example, it is estimated that the fuel capacity of a destroyer would permit about nine days operation at 15 knots (a good representative enroute cruising speed) plus six hours at 25 knots (operational speed), without dropping below 50% tankage. Customarily, for reasons of water stability in rough weather, destroyers do not operate at all with less than 50% fuel for ballast; there is a decided preference for refueling substantially in advance of the 50% point. Therefore, a destroyer covering the

TABLE 29

DETECTION AND SEARCH AIRCRAFT CYCLE DATA

Reference: Figure 56

Area Number	Station Number(1)	Distance to Station N. Mi.	Distance to Station From Base	Capsule Arrival(2)	Impact Distance From Station	Impact Distance From Base	Latest Retrieve(2)	Aircraft Type	Installed Radar	Take-off Time(2)	Time to Station	Permissible Hold(3)	Advance Time(4)
1	1	0	Patrick	0:00	220	220	3:00	S2F SA-16A/B	X-Band X-Band	(5) (5)	— —	— —	0:55 1:00
2,7	2*	420	Patrick	0:06/3:24	40	410	6:24(6)	SA-16A/B P5M-2	X-Band C-Band	-3:39 -3:23	3:39 3:23	3:56/8:50 8:47	2:34 2:37
2,7	Retrieve Airship	250	Bermuda	0:06	(7)	(7)	—	Airship	S-Band	-6:15	6:15	(8)	—
2	3*	140	Bermuda	0:06	60	90	5:48	SA-16A/B P5M-2	X-Band C-Band	-1:13 -1:05	1:13 1:05	10:24/15:42 14:32	5:00 5:04
2,6	4*	120	Bermuda	0:09/1:42	50	90	4:42(9)	SA-16A/B P5M-2	X-Band C-Band	-1:00 -0:52	1:03 0:55	11:37/16:49 15:40	2:29 2:32
2,6	Retrieve Airship	250	Bermuda	0:09	(7)	(7)	—	Airship	S-Band	-6:12	6:15	(8)	—
2	5*	440	Bermuda	0:09	40	480	6:09	P5M-2 P2V-5/7	C-Band S-Band	-3:20 -2:53	3:23 2:56	8:17 10:39	5:28 5:30
2	6	750	Bermuda	0:12	260	1,010	5:12	P5M-2 P2V-5/7 WV-2	C-Band S-Band S-Band	-5:40 -4:54 -3:45	5:46 5:00 3:51	2:00 5:13 6:13	2:43 3:00 3:23
3,4	7	610	Lajez, Azores	0:15	290	820	4:15	SA-16B P5M-2 P2V-5/7 WV-2	X-Band C-Band S-Band S-Band	-5:10 -4:33 -3:55 -2:59	5:19 4:42 4:04 3:08	4:30 5:49 8:43 9:22	1:09 1:26 1:44 2:11
5	8	0	Canary Is.	0:20	130	130	2:20	S2F SA-16A/B	X-Band X-Band	(5)	— —	— —	0:31 0:34
8	9(10)	0	Dominican Rep. AAFB	5:00	270	270	8:00	S2F SA-16A/B	X-Band X-Band	(5) (5)	— —	— —	0:28 0:34
Area 8 Overshoot	10(10)**	0	Antigua	5:00	790	790	14:12	SA-16B P5M-2 P2V-5/7	X-Band C-Band S-Band	(5) (5) (5)	— — —	— — —	2:15 3:02 3:51

NOTES:
1. Reference Figure 56
2. Launch taken as 0:00 time reference, all times in hr.:min.
3. No relief, time interval given.
4. Search contact obtained in advance of arrival of retrieve vehicle, time interval given.
5. Take-off 5 min. after impact.
6. Orbit 2 landing at 3:24, plus 3 hours.
7. Airships not used for search.
8. Airship time in air capabilities exceeds two days.
9. Orbit 1 landing at 1:42, plus 3 hours.
10. One P2V-5/7 or WV-2 on ground at San Juan could cover both Area 8 and overshoot, impact distances of 370 n. mi. in Area 8 and 1,050 n. mi. in overshoot.

* Not required in minimum cost complex; replaced by one SA-16A/B on ground standby at Bermuda.

** Not included in minimum cost complex.

ship station most remote from Norfolk, over six days travel, will require refueling and perhaps other logistics support quite independent of the length of time spent on station through whatever holds and delays that occur. Even stopping at Bermuda for fuel between Norfolk and station would not avoid the need for refueling because almost four and one-half days travel each way would be required between Bermuda and station, or almost nine days for the round trip. Thus, even if there were to be no delay whatsoever, the operation would be marginal.

The same situation would be found applicable to other ship stations, with considerable variation in severity because of the widely differing enroute times required. However, there would still be a very real need for normal logistics support of fuel supply. Additionally, ordinary caution would call for support being made available to guard against attrition due to equipment or vessel malfunction.

As an alternative procedure, one might logically consider recycling in place of continued logistic support at sea in the event of long delays. Referring to Table 28 , the longest staging time shown is somewhat in excess of six days. Therefore, the entire ship complex could be recycled in about thirteen days travel, plus the time in port necessary for re-supply.

OPERATIONAL EFFECTIVENESS

A high probability of recovery in a short time and at low cost are the goals emphasized in this study. While previously each of the many considerations has been discussed in its own chapter, in this section the interactions among these three main factors are evaluated and their interrelationships are shown. A procedure is developed and illustrated with an example to indicate how a given vehicle deployment complex may be analyzed and the answers found to the questions:

What are the chances of recovering the capsule?
How long will it take?
What will it cost?

Three different vehicle complexes have been studied in this report. As described in some detail, beginning on page 171, they are characterized by:

1. Exclusive use of aircraft for detection and search; detection possible to the surface throughout the high probability impact areas. Any possibility of detection from the retrieve surface vehicles is neglected.

2. Use of both aircraft and ships for detection; continuous detection capability in the high probability impact areas for chaff, 10,000 feet to 8,000 feet altitude.

3. Minimum cost system similar to (2), above, except that the detection vehicles are spaced further apart.

The first of these systems differs from the other two in that it permits the utilization of retrieve vehicles which do not possess suitable detection equipment. The third system differs from the previous two in that continuous coverage for detection before impact is no longer a system requirement. Thus, examination of these systems can show the relative values of:

1. Continuous detection coverage in the high probability impact areas as opposed to a system without this requirement.

2. Employing all vehicles as detectors as opposed to using only especially designated detection vehicles.

3. Maximum spacing of detection aircraft as opposed to spacing for minimum search time.

The relationship between the assumed total recovery time and the allowable search time is shown in the following expression:

$$T_t = \frac{1}{12} + \frac{S}{V_s} + t_s + \frac{R}{V_r} + \frac{1}{6}$$

where T_t = assumed total recovery time (hours)

$\frac{S}{V_s} + t_s$ = allowable search time = T_a

S = initial distance from detection or search vehicle to predicted impact point

V_s = velocity of the search vehicle

t_s = time required to search the uncertainty area

R = radius of uncertainty area

V_r = velocity of retrieve vehicle

$\frac{1}{12}$ = 5 minutes immediately after impact to allow for local coordination of search effort

$\frac{1}{6}$ = 10 minutes for final maneuvering of the retrieve vehicle and for pick-up of the capsule from the water

$\frac{S}{V_s}$ = time for search vehicle to travel from initial station to predicted impact point

$\frac{R}{V_r}$ = time for retrieve vehicle to travel from predicted impact point to circumference of uncertainty area

System effectiveness, E, is here defined as the probability that the capsule will be located in sufficient time for recovery to be completed within the assumed total recovery time. The values shown for E are derived from:

1. The probability of detection before impact averaged over the distance from the nearest detection vehicle.

2. The search time actually available to the search vehicle after travel to impact area, and the corresponding probability that the search results in a successful detection within the allowable search time.

3. The reliability of detection and search equipment.

Since a local area detection results in almost certain success in search and retrieval, system effectiveness may be considered to be the same as the probability of detection of the capsule by the local recovery forces:

Restriction/
Classification
Cancelled

Confidential

TABLE 30

RECOVERY SYSTEM EFFECTIVENESS

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Recovery Area		Assumed Total Recovery Time (hrs.)	Estimated Radius of Uncertainty (n. mi.)	Retrieve Vehicles				Allowable Search Time (hrs.)	Detection and Search Systems				
No.	Dimensions			No.	Type	Velocity	Average Velocity		Complete Coverage for Chaff at 8000' Aircraft and Ships		Complete Surface Coverage Aircraft Only		Either System
						(knots)			Capsule Location Aid Availability				
									No Capsule Aids				All Aids or Chaff Only
									After Impact (P_s R2)	Total (E)	After Impact (P_s R2)	Total (E)	Total (E)
1	100 x 300	3	3.6	1 2	HR2S DD	90 25	47	2.63	0.94	0.96	0.94	0.94	0.99
2	40 x 1600	6	30	2 1 2	ZP HUS DD	40 85 25	43	5.05	0.90	0.94	0.90	0.90	0.99
3	40 x 200	6	30	1	DD	25	25	4.55	0.90	0.94	0.90	0.90	0.99
4	40 x 200	6	30	1	DD	25	25	4.55	0.90	0.94	0.90	0.90	0.99
5	40 x 200	3	3.6	1	HR2S	90	90	2.71	0.94	0.96	0.94	0.94	0.99
6	50 x 210	3	3.6	1	ZP	40	40	2.66	0.94	0.96	0.94	0.94	0.99
7	50 x 210	3	30	1 1	ZP DD	40 25	33	1.84	0.49	0.67	0.55	0.55	0.99
8	120 x 400	3	3.6	2	ZP	40	40	2.66	0.94	0.96	0.94	0.94	0.99

E = Recovery System Effectiveness (including equipment performance, reliability, recovery time and search vehicle velocity)
= $P_d \cdot R_1 + (1 - P_d \cdot R_1)\, P_s \cdot R_2$ (where R_1 and R_2 are reliability factors as a function of time before and after impact, respectively)
(where P_d is probability of detection before impact as a function of equipment performance capability and time available for detection.)
(where P_s is probability of detection after impact as a function of equipment performance capability, time available for searching, size of area to be searched and search vehicle velocity.)

P_d from Figures 43 and 10. (11) = (0.35) (0.98) + (1 - 0.35 x 0.98) x (10)

R_1 and R_2 from Figure 30. (13) = (0.01) (0.98) + (1 - 0.01 x 0.98) x (12)

P_s from section on search after impact. (14) = (0.99) (0.98) + (1 - 0.99 x 0.98) ($P_s \cdot R_2$), where $P_s R_2 \geq 0.49$ in all cases.

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$$E = P_d R_1 + (1 - P_d R_1) P_s R_2$$

where P_d = Probability of detection before impact as a function of equipment performance capability and time available for detection

P_s = Probability of detection after impact as a function of equipment performance capability, time available for searching, size of area to be searched and search vehicle velocity

R_1 and R_2 = Reliability factors as a function of particular equipment and the length of time during which it operates before and after impact, respectively.

Table 30 lists the high-probability impact area parameters and shows the recovery system effectiveness for each area for the preferred deployment of retrieve vehicles (Figure 51). Two different vehicle arrangements for detection before impact are assumed (Figures 56 and 57) with three conditions of capsule location aid availability. The two detection systems give 1) complete radar beacon coverage of the surface and 2) complete radar coverage for chaff down to 8,000 feet altitude.

With either detection system there is a greater than 99% probability of recovery within the assumed recovery time when the capsule location aids work. Probability is still 99% if all capsule electronic aids fail and only the chaff functions as planned at the main parachute opening. If no location aids function (no C-band, S-band, UHF, HF or SARAH beacons, no chaff, smoke, dye marker or flashing light), the probability of locating the capsule within the assumed 3 hour or 6 hour maximum recovery time is reduced to 90 - 94% throughout most of the area. It can be increased either by adding more vehicles or more search time. For area 7, with no capsule aids or chaff detection, the 55% probability can be increased to 99% by the addition of one-half hour to the originally assumed 3 hour recovery time.

It is considered beyond the scope of this brief study to include the probability of various capsule location aids operating. The probability that the capsule is more likely to land in one of the high-probability areas than in another is neglected also except insofar as recovery forces are reduced in abort areas 2, 3 and 4 consistent with a maximum recovery time of 6 hours in contrast with the 3 hour maximum assumed for all the other areas.

The third detection and search vehicle complex, based on minimum cost, is similar to that for complete chaff coverage except that the four aircraft at flight stations 2,3,4 and 5 (for Area2) shown in Figure 56 are replaced by one on the ground at Bermuda. The maximum search vehicle spacing is reached when further reduction in the number of search vehicles would result in an increase in total system cost due to the need for additional retrieval vehicles.

This case is examined in the following example which serves to show a procedure for checking the recovery system effectiveness for a given deployment of vehicles in a particular area.

Example:

Area: Area No. 2
Dimensions: 40 x 1600 miles
Assumed total recovery time (T_t): 6 hours
Estimated radius of uncertainty (R): 30 miles

Retrieve Vehicles: (Fig. 51)
Two airships, 40 knots
One HUS helicopter, 85 knots
Two destroyers, 25 knots
Average vehicle velocity (V_r): 43 knots

Detection stations for chaff:
One fixed-wing aircraft
Two airships
Two destroyers
One ground station (Bermuda)

Total = 6

Detection station range = 120 miles (line-of-sight limited against chaff at 10,000 - 8,000 ft.)

Average detection station spacing = 1600/6 = 267 miles.
Because of some overlapping coverage, spacing is assumed to be 300 miles.

Average range per station required for complete coverage = 300/2 = 150 miles.

P_d, when chaff is available for detection from shipboard, airship or land-based radar = .99 x 120/150 = .79 (A 99% probability is assumed over the line-of-sight range of 120 miles and 0% over the remaining 30 miles) based on radar performance.

P_d, If no chaff or other location aids operate, probability of detection before impact is assumed = .99 x 60/150 = .40, based on a range skin tracking of capsule alone of 60 out of the 150 miles total. (An assumed average range for the airborne, shipboard, and ground radars).

R_1 = Reliability of the shipboard and land-based radars during the short time before impact is assumed to be at least 99%.

$P_d \times R_1$ = Minimum probability of detection before impact
against chaff = .99 x .79 = .78
no location aids = .99 x .40 = .39

Search vehicle stations: one aircraft at Bermuda
(Fig. 56) one aircraft at eastern end of area 2

Maximum search vehicle spacing = 800 miles
Length of track to be covered by each = 400 miles to either side
Search vehicle velocity = 150 knots
Maximum time to predicted impact point = 400/150 = 2.67 hours

Allowable search time = $T_a = T_t - \frac{1}{12} - \frac{R}{V_r} - \frac{1}{6}$ (From the equation on page 198)

$$= 6 - \frac{1}{12} - \frac{30}{43} - \frac{1}{6}$$

$$= 5.05 \text{ hours}$$

Time remaining to search uncertainty area = 5.05 - 2.67 = 2.38 hours

Sweep width of search vehicle (all aids), W = 124 miles (Figure 45)

2 x 62 mile range capability of UF or S2F aircraft. It can be seen from Figure 45 that several other aircraft have greater equipment capability. The value from Figure 45 is the range for 0.5 probability of detection in a single scan. It is assumed there will be time to get at least 7 scans and so raise the probability to a level greater than .99.

Sweep width of search vehicle (no aids), W = 25 miles, derived as follows:

1) Radar range against capsule (as a snorkel) = 18 miles (Table 8) for 50% probability of detection, for a single scan, for zero sea state.

2) For average sea conditions (state 2-3) range reduction factor = .70, giving an effective range of .70 x 18 = 12.5 miles (see sketch on page 41) or sweep width = 2 x 12.5 = 25 miles.

Track spacing (all aids) = 0.4 x 124 = 50 miles.

Track spacing (no aids) = 0.4 x 25 = 10 miles. Figure 14 shows that track spacing should be approximately 0.4 x sweep width for minimum time to obtain a 0.99 detection probability.

Time required to search the 30 mile radius uncertainty area:

1) All capsule aids functioning, t=0 hours (Detection range is over twice the radius of uncertainty area).

2) No capsule aids functioning, t = 1.88 hours = $\frac{d}{V_s} = \frac{A}{0.4\, WV_s}$ for a search of the completion area.

A search with .99 probability of detection could be made in 1.07 hours (Equation 12, page 61).

P_s = Probability of detection during remaining search time (neglecting reliability)

1) All capsule aids = .99
2) No capsule aids = .99 (1.88 2.38 hours allowed)

R_2 = Reliability of the aircraft equipment during the search.

1) All aids = .95 (Fig. 30, for radar at 0.5 hours)
2) No aids = .89 (Fig. 30, for radar at 1.88 + 0.5 hours)

$P_s \times P_2$ = Probability of detection after impact within allowed time.

1) All aids, $> .99 \times .95$ or $> .94$
2) No aids, $= .99 \times .89$ or $= .88$

E = Recovery System Effectiveness (from the equation on page 199)

1) All capsule aids functioning, $= .78 + (1-.78)\ .94$
$= \underline{.99}$

2) Only chaff available, $= .78 + (1-.78)\ .88$
$= \underline{.97}$

3) No capsule aids available, $= .39 + (1-.39)\ .88$
$= \underline{.93}$

The above Effectiveness values for this minimum cost type of detection system, with more widely spaced detection vehicles, compare with .99, .99 and .94, respectively, for the deployment that gives complete coverage for chaff (Table 30). The slight difference between the two systems, for the cases where the capsule location aids are not functioning, is explained by the fact that if no initial local contact is made before impact, a greater area of uncertainty must be searched. This will take more time and the reliability of the search equipment continues to drop off with time. The difference is not important for the short search times that are due to combining these proposed recovery forces and small uncertainty areas.

Total Cost of the Recovery Systems. The total operational cost of the recovery for the 3 complexes described is itemized in Tables 31 and 32 and is shown in Figure 59 as a function of the number of daily postponements. The detailed cost summary is given in Appendix A.

The total cost may be summarized as follows:

	Minimum Mission	Mission including 10 Daily Postponements
Complete Surface Detection Coverage	$740,500	$1,641,600
Complete Chaff Detection Coverage	689,700	1,510,300
Minimum Cost	679,300	1,458,300

TOTAL COST OF RECOVERY OPERATION

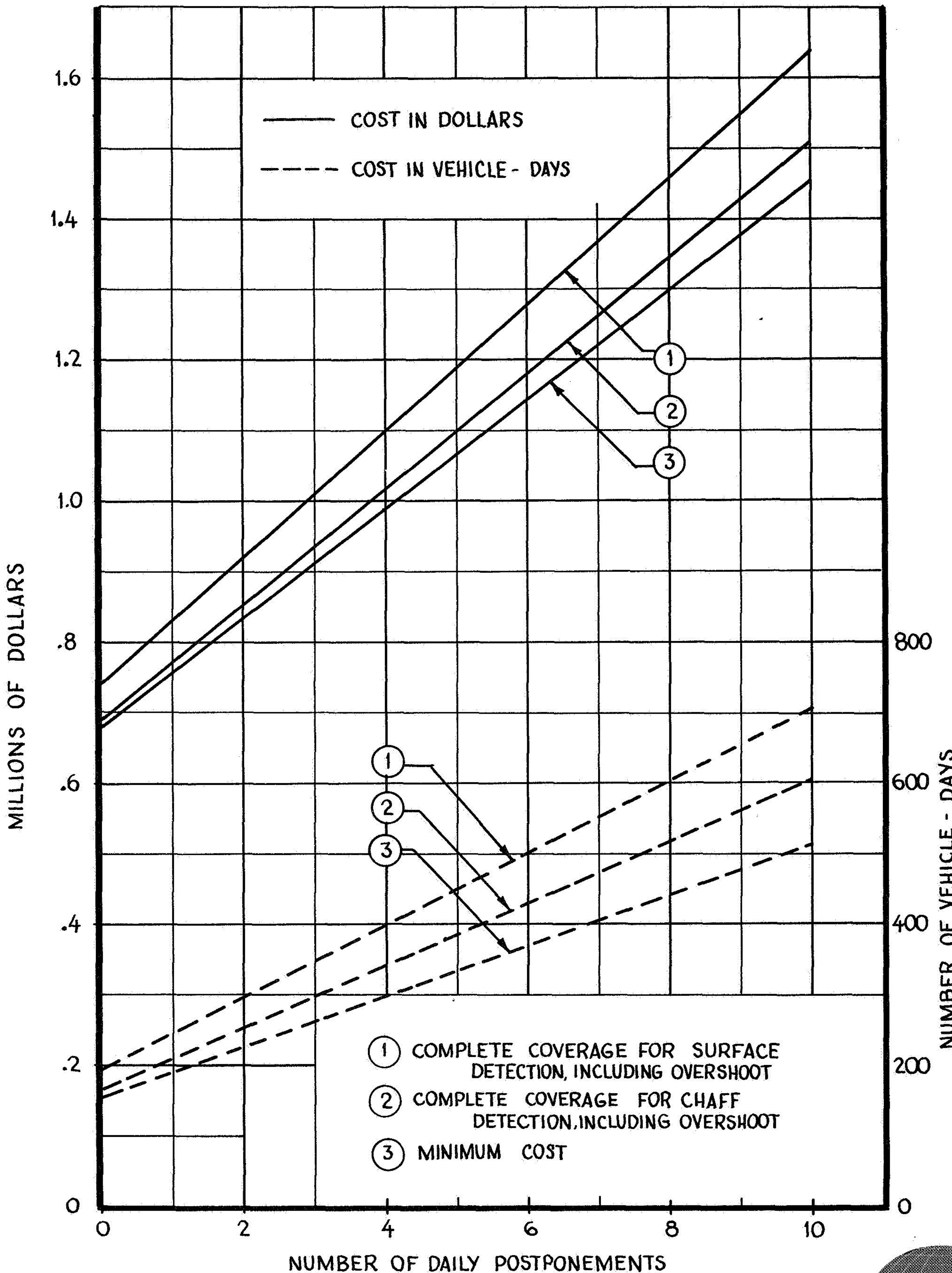

FIG. 59

The cost for the minimum recovery mission - assuming no delays or postponements - is therefore about $700,000 in direct expenses: including fuel, oil, and other consumables, an apportioned share of the maintenance, and pay and allowances of the military personnel involved. The cost will double if 8 or 9 daily postponements are required.

The commitment of vehicles to the operation can be reduced substantially if complete local detection coverage is not required. The minimum cost complex requires from 20 to 25% fewer vehicle-days than that for complete surface detection coverage. On the other hand, the increase in operational cost required for complete local detection coverage is relatively small: a 1 to 4% increase for complete coverage for chaff, and a 9 to 13% increase for complete coverage for surface detection.

Recommended Recovery System

The three vehicle complexes discussed are considered to be minimum systems for the type of local detection coverage they provide. The choice as to the optimum selection and allocation of recovery forces is left to the authority responsible for the safe recovery of the Mercury capsule and its occupant, to be decided on the basis of their effectiveness, their cost, their availability, and whatever intangible factors are construed to be significant.

TABLE 31

TOTAL COST SUMMARY - MINIMUM MISSION

OPERATING COST IN THOUSANDS OF DOLLARS AND (VEHICLE-DAYS)

Vehicles/Area		1	2	3	4	5	6	7	8	Overshoot	Total
Retrieving Vehicles											
(All Complexes)											
Helicopter	(HS)	$ 0 (2)	$ 2.0 (12)	-	-	$ 8.6 (20)	(a)	(a)	-	-	$ 10.6 (34)
Airship	(ZP)	-	58.4 (12)	-	-	-	(a)	(a)	$ 93.6 (28)	-	152.0 (40)
25-knot Ship	(DD)	29.6 (3)	201.4 (19)	$116.8 (11)	$139.5 (13)	-	(a)	(a)	-	-	487.3 (46)
Total Retrieving Vehicles		$29.6 (5)	$261.8 (43)	$116.8 (11)	$139.5 (13)	$ 8.6 (20)	(a)	(a)	$ 93.6 (28)	-	$649.9 (120)
Detection Vehicles											
(Minimum Cost Complex)											
S2F		-	-	-		$11.6 (14)	(a)	(a)	$ 3.2 (6)	-	$ 14.8 (20)
SA-16 (UF)		$ 0 (2)	$ 0 (2)	$11.5 (10)		-	(a)	(a)	-	-	11.5 (14)
P5M		-	3.1 (2)	-		-	(a)	(a)	-	-	3.1 (2)
Total Detection Vehicles		$ 0 (2)	$ 3.1 (4)	$11.5 (10)		$11.6 (14)	(a)	(a)	$ 3.2 (6)	-	$ 29.4 (36)
(Complete Chaff Detection Complex)											
S2F		$ 0 (2)	-	-		$11.6 (14)	(a)	(a)	$ 3.2 (6)	-	$ 14.8 (22)
SA-16 (UF)		-	$ 2.6 (6)	$11.5 (10)		-	(a)	(a)	-	$ 5.8 (6)	19.9 (22)
P5M		-	5.1 (4)	-		-	(a)	(a)	-	-	5.1 (4)
Total Detection Vehicles		$ 0 (2)	$ 7.7 (10)	$11.5 (10)		$11.6 (14)	(a)	(a)	$ 3.2 (6)	$ 5.8 (6)	$ 39.8 (48)
(Complete Surface Detection Complex)											
P5M		-	$ 7.0 (7)	-	-	-	(a)	(a)	-	-	$ 7.0 (7)
P2V		$ .4 (2)	-	$12.8 (10)	$12.1 (10)	$17.6 (14)	(a)	(a)	$ 9.6 (12)	$18.8 (18)	$ 71.3 (66)
WV-2		-	12.3 (4)	-	-	-	(a)	(a)	-	-	12.3 (4)
Total Detection Vehicles		$ .4 (2)	$ 19.3 (11)	$12.8 (10)	$12.1 (10)	$17.6 (14)	(a)	(a)	$ 9.6 (12)	$18.8 (18)	$ 90.6 (77)
Total System Cost											
Minimum Cost Complex		$29.6 (7)	$264.9 (47)	$267.8 (34)		$20.2 (34)	(a)	(a)	$ 96.8 (34)	-	$679.3 (156)
Complete Chaff Detection Complex		$29.6 (7)	$269.5 (53)	$267.8 (34)		$20.2 (34)	(a)	(a)	$ 96.8 (34)	$ 5.8 (6)	$689.7 (168)
Complete Surface Detection Complex		$30.0 (7)	$281.1 (54)	$129.6 (21)	$151.6 (23)	$26.2 (34)	(a)	(a)	$103.2 (40)	$18.8 (18)	$740.5 (197)

(a) Included in Area 2

TABLE 32

TOTAL COST SUMMARY - MISSION INCLUDING 10 DAILY POSTPONEMENTS

OPERATING COST IN THOUSANDS OF DOLLARS AND (VEHICLE-DAYS)

VEHICLES/AREA	1	2	3	4	5	6	7	8	Overshoot	Total
Retrieving Vehicles										
(All Complexes)										
Helicopter (HS)	$ 0 (22)	$ 2.0 (52)	-	-	$ 8.6 (60)	(a)	(a)	-	-	$ 10.6 (134)
Airship (ZP)	-	155.4 (52)	-	-	-	(a)	(a)	$ 93.6 (68)	-	249.0 (120)
25-Knot Ship (DD)	135.9 (13)	520.5 (49)	$223.2 (21)	$245.9 (23)	-	(a)	(a)	-	-	1125.5 (106)
Total Retrieving Vehicles	$135.9 (35)	$677.9 (153)	$223.2 (21)	$245.9 (23)	$ 8.6 (60)	(a)	(a)	$ 93.6 (68)		$1385.1 (360)
Detection Vehicles										
(Minimum Cost Complex)										
S2F	-	-	-		$ 11.6 (34)	(a)	(a)	$ 3.2 (26)	-	$ 14.8 (60)
SA-16 (UF)	$ 0 (22)	$ 0 (22)	$27.6 (30)		-	(a)	(a)	-	-	27.6 (74)
P5M	-	30.8 (22)	-		-	(a)	(a)	-	-	30.8 (22)
Total Detection Vehicles	$ 0 (22)	$ 30.8 (44)	$27.6 (30)		$ 11.6 (34)	(a)	(a)	$ 3.2 (26)		$ 73.2 (156)
(Complete Chaff Detection Complex)										
S2F	$ 0 (22)	-	-		$ 11.6 (34)	(a)	(a)	$ 3.2 (26)	-	$ 14.8 (82)
SA-16 (UF)	-	$ 26.0 (66)	$27.6 (30)		-	(a)	(a)	-	$ 5.8 (26)	59.4 (122)
P5M	-	51.0 (44)	-		-	(a)	(a)	-	-	51.0 (44)
Total Detection Vehicles	$ 0 (22)	$ 77.0 (110)	$27.6 (30)		$ 11.6 (34)	(a)	(a)	$ 3.2 (26)	$ 5.8 (26)	$ 125.2 (248)
(Complete Surface Detection Complex)										
P5M	-	$ 70.1 (77)	-	-	-	(a)	(a)	-	-	$ 70.1 (77)
P2V	$ 4.3	-	$ 34.7 (30)	$ 27.5 (30)	$ 17.6 (34)	(a)	(a)	$ 9.6 (52)	$18.8 (78)	112.5 (246)
WV-2	-	73.9 (24)	-	-	-	(a)	(a)	-	-	73.9 (24)
Total Detection Vehicles	$ 4.3 (22)	$144.0 (101)	$ 34.7 (30)	$ 27.5 (30)	$ 17.6 (34)	(a)	(a)	$ 9.6 (52)	$18.8 (78)	$ 256.5 (347)
TOTAL SYSTEM COST										
Minimum Cost Complex	$135.9 (57)	$708.7 (197)	$496.7 (74)		$ 20.2 (94)	(a)	(a)	$ 96.8 (94)	-	$1458.3 (516)
Complete Chaff Detection Complex	$135.9 (57)	$754.9 (263)	$496.7 (74)		$ 20.2 (94)	(a)	(a)	$ 96.8 (94)	$ 5.8 (26)	$1510.3 (608)
Complete Surface Detection Complex	$140.2 (57)	$821.9 (254)	$257.9 (51)	$273.4 (53)	$ 26.2 (94)	(a)	(a)	$103.2 (120)	$18.8 (78)	$1641.6 (707)

(a) Included in Area 2.

III RECOVERY IN LOW PROBABILITY IMPACT AREAS

III. RECOVERY IN LOW PROBABILITY AREAS

The planned Mercury three-orbit mission is to include provisions for abort during launch or at insertion into orbit, and for landing at the end of each orbit should that be necessary. It is from these points that the eight high probability impact areas - their locations, their sizes, their access times - have been derived. Thus far, the report has been devoted primarily to recovery of the manned capsule from any of the high probability areas, all of which lie within the Atlantic Ocean between 18° and 33° north latitude and between Florida and the northwestern coast of Africa, roughly one-sixth of the earth's circumference.

There still remains the lesser probability of an impact occurring somewhere in the other five-sixths of the earth's circumference, along the combined track of the planned three orbits. This might occur in the event of an in-flight emergency requiring an immediate return rather than a return at the next point provided for in advance. Should such an impact occur, a recovery operation would of course be required; consideration of its importance has prompted the inclusion of a brief discussion of recovery in low probability areas.

The world-wide network of communications and tracking stations has been set up to give very extensive coverage for the over-all three-orbit mission track. With this total network, it is anticipated by NASA that if a re-entry occurs anywhere along the track:

1. It will be known that re-entry has occurred.
2. The approximate location of re-entry will be known.
3. The approximate area and time of impact will be known.

The amount of uncertainty associated with each one of these "known" facts may be appreciable. However, the important point is that a completely random impact location need not be anticipated, although one could occur if there were a communications and tracking system failure as well as a failure of an emergency nature in the capsule, an extremely improbable eventuality.

It may therefore be assumed that no world-wide recovery effort would have to be mounted, merely world-wide provisions of a secondary or back-up nature. Among the attractive world-wide facilities and agencies would be:

1. Strategic Air Command aircraft disposed at SAC and other military bases around the world. The U.S. operated bases are located principally north of the equator, as indicated by Figure 60, but certain types of SAC aircraft have very long range capabilities which would permit substantial operation in the southern hemisphere.

2. Other United States military forces using aircraft types ordinarily based world-wide.

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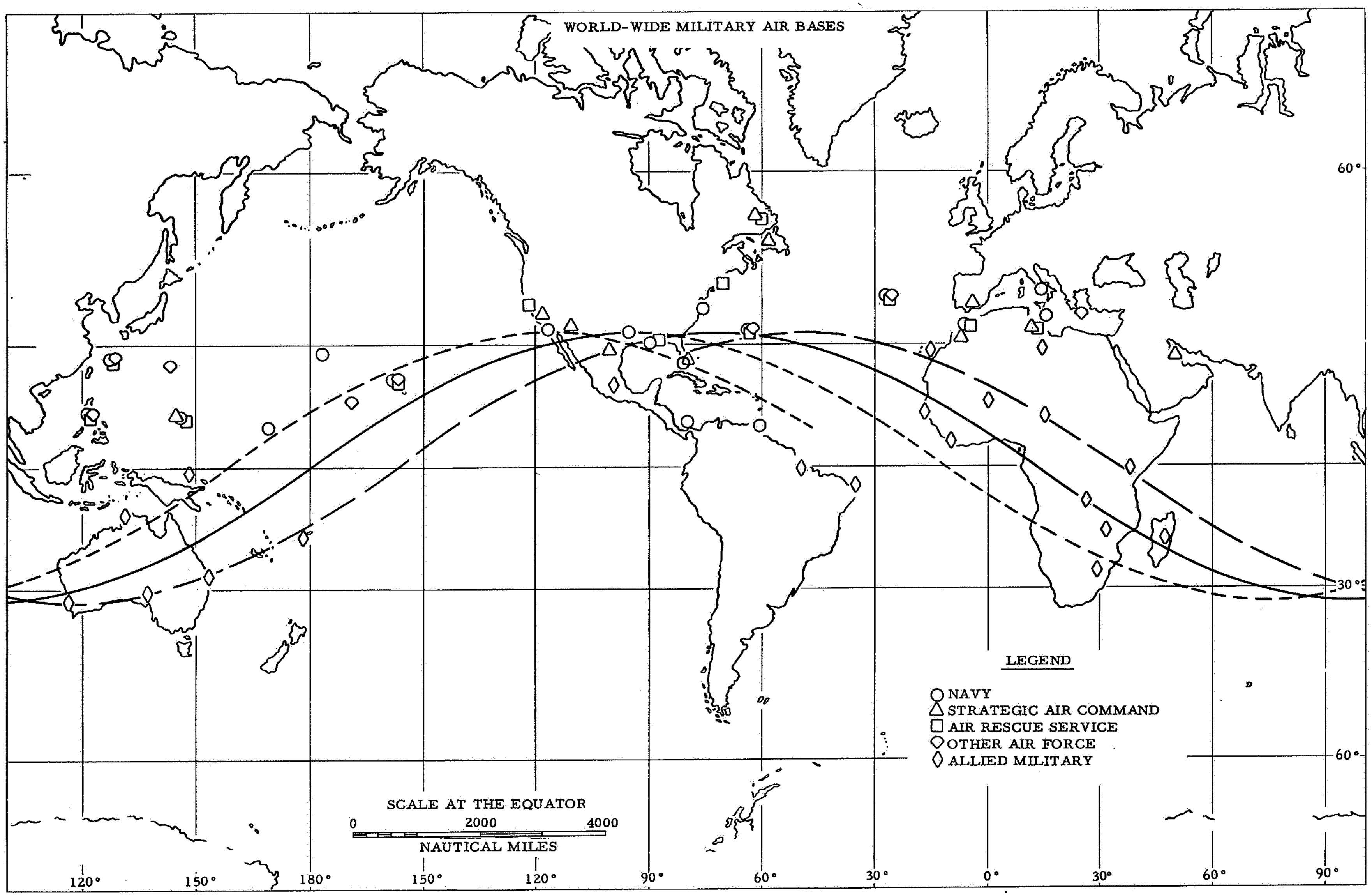

FIG. 60

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3. Military forces and bases of friendly nations, including possible temporary basing of U.S. forces.

4. Civil operated aircraft and merchant shipping vessels. Under customs and internationally recognized laws of the sea, virtually all ships would be bound to lend assistance to a vessel in distress, and the capsule could be considered as such in the event of impact in a low probability area.

All of these possible areas of support should be obtainable on a stand-by or back-up basis, given sufficient and proper advance coordination and notification of planned firing time.

The first possibility, use of SAC capabilities, has been examined briefly in the form of a survey of aircraft performance, Tables 4 and 5, and Figure 6, and of airbase locations on a world map, Figure 60. The world map is repeated in somewhat less detail as Figure 61, with circles added to bracket the maximum mission radius capabilities of the SAC aircraft types considered herein (KC-97, B-52, B-47, KC-135). As may be seen, the entire three-orbit mission track may be covered by SAC aircraft operating from Florida, Morocco, Saudi Arabia, Manila, Guam, and Honolulu. The circles included in Figure 61 apply specifically to the B-47 (smaller circle) and B-52(larger circle), and indicate the lowest and highest radius extremes of the spread in maximum radius capability among the four SAC aircraft types.

Perhaps the most serious question with regard to recovery in the low probability part of the track is that of capsule location aids. The area uncertainty associated with impact may be extremely large as compared with aircraft search rates, but more important, the combination of high speed and high altitude might tend to prevent successful visual search. Of the four SAC aircraft types considered, none would be able to operate at good search speeds, and only the KC-97 could operate at the required very low altitude without great penalty in range or radius. Other types of long range aircraft, such as the long-range Douglas DC-7C and Lockheed Super Constellation commercial transports, which might be considered, also are characterized by high search speeds; further, their range capabilities, although substantial, are considerably less than those of the four SAC types. In addition, all of the longer range aircraft types, both military and civil, exhibit considerably less than ideal window number, size, and location for use of visual search observers.

It therefore becomes evident that far greater reliance will be placed on the electronic location aids of the capsule in the event of impact in a low probability area than need be the case with a planned impact in a monitored high probability area. Insofar as the electronic aids operate and can be homed on, success in the final visual search should be less sensitive to the aircraft operating speed-altitude characteristics. Because of the critical nature of the electronic location aids, aircraft to be considered for detection and search should be checked carefully for compatibility of their installed equipments to the capsule aids.

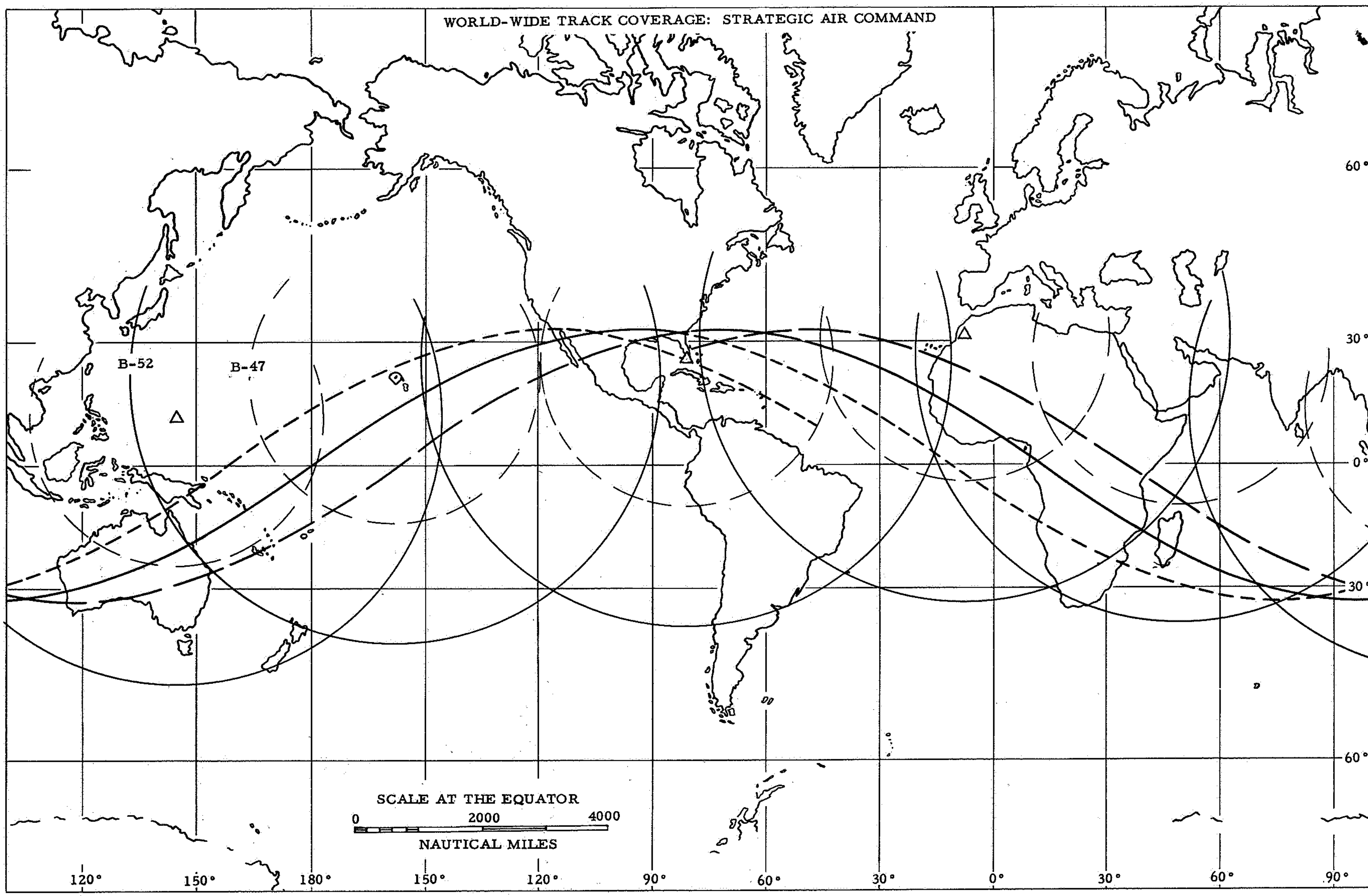
WORLD-WIDE TRACK COVERAGE: STRATEGIC AIR COMMAND
B-52
B-47
SCALE AT THE EQUATOR
0
2000
4000
NAUTICAL MILES
60°
30°
0°
30°
60°
120°
150°
180°
150°
120°
90°
60°
30°
0°
30°
60°
90°

FIG. 61

In order to guard against confusion in homing, such as might be caused by weak signal, atmospheric interference, or transmission by others on the capsule frequencies, it might be advisable to equip the capsule with some means for determining geographical position. Then, if the occupant is able, he could determine his approximate position and transmit the information through the voice communications channels available. This procedure might thus obviate the need for strict dependence on homing the beacons or other electronic radiation, and give a measure of additional back-up to the system.

Retrieve in the low probability areas along the track is more difficult to visualize. Once the capsule is found by a detection and search aircraft, that aircraft could vector other vehicles to the scene. Retrieve might be effected by:

1. Military forces, United States or friendly nation.
2. Merchant ships in the general area.
3. Seaplanes able to land and rescue the occupant from the capsule.
4. Para-medical team, large raft, and supplies dropped near capsule to remove and care for occupant while awaiting the arrival of a ship.

The advantage of a fixed wing aircraft retrieve technique workable by the detection and search aircraft would be quite substantial in terms of the amount of time required for completion of the recovery effort.

It is recommended that the problem of recovery in low probability areas of the world, especially along the three-orbit mission track, be subjected to further study in its own right.

IV FUTURE DEVELOPMENT CONSIDERATIONS

IV. FUTURE DEVELOPMENT CONSIDERATIONS

The success of any recovery system is dependent upon how accurately the landing area can be predicted. It is obvious that if the present recovery areas could be reduced in size, the number of recovery units could be reduced accordingly. At the same time, the costs would be greatly decreased and more effort could be put into making the fewer recovery units more effective even to the point of designing and building vehicles with just the specific purpose of recovery. The ultimate in recovery efficiency and economy will, of course, be achieved when the impact area can be reduced, through accurate guidance or control means, to a size which would permit a landing in a small prepared area.

For the purposes of this study, however, it is assumed that the impact areas are the same as those currently conceived. Emphasis is placed on the ideas or systems found during the course of the study which, while possibly not ready at present for the first orbital flights, show the greatest promise for improving the recovery operation in the future. The improvement is shown as a reduction in either vehicles required or access time.

FIXED WING AIRCRAFT

There are several ways in which the use of fixed wing aircraft for retrieve would be an attractive development. First and foremost is the possibility of obtaining very short access times, or short access times combined with a small number of vehicles required. Second, there is the possibility of using the same vehicle for detection and search and for retrieve, thus removing one vehicle complex from the over-all scheme. A third attractive feature of such a system would be its greater versatility with respect to location of areas to be monitored, as compared with a system containing ships, which are slow, and helicopters, which are relatively slow and limited in range.

In deploying aircraft for use of one of the retrieve techniques discussed below, a distinction must be made between an air-to-air snatch and a water-to-air pick-up, the latter being either a snatch or a long-line procedure. If an air-to-air snatch is to be made, time and timing are very critical, whereas for the water-to-air pick-ups, time and timing are of considerably less importance, though positional accuracy will still be critical.

Air-To-Air Retrieve

All American Engineering Company, Wilmington, Delaware, has pioneered in this type of recovery. Their method of recovering a parachute-borne object is shown in Figure 25. The system consists of two booms about 10 feet apart at the top and 20 feet apart at the bottom and extending downward 30 feet from the opened rear cargo door of a C-119, C-130, or similar cargo type airplane. Suspended across the tips of the booms is a nylon line containing several special hooks. This line is carried up the booms to a powered winch in the hull. The pilot of

the aircraft flies a course so as to intercept the drogue parachute with the hooks. This drogue parachute is made with specially reinforced shroud lines extending over the canopy and down to the main parachute and capsule and strong enough to support it. The winch system is capable of reeling in parachutes, shroud lines, etc., in order to bring the capsule into the aircraft through the cargo door.

This system is attractive because (1) it is fast, (2) it eliminates the hazards of the sea, and (3) it is relatively inexpensive. However, the heaviest weight retrieved so far in the air is 1000 pounds, using C-119 aircraft. All American has, at one time, estimated 6 to 8 months to engineer and develop a prototype system in a C-130 airplane suitable for retrieving the Mercury capsule. Production installations and a training program would then follow.

Disadvantages of the air-to-air pick-up are (1) special redesign (and therefore reliability testing) of a new stronger parachute system, (2) specialized training and skilled piloting required for aircraft crew, (3) not suitable for night or poor visibility conditions, (4) density of recovery aircraft in predicted impact area must be great enough to insure interception within the relatively short time during which the capsule is within the aircraft's altitude capabilities. The bulk of the stronger parachute system may prove a problem of storage and ejection in the capsule. Much training and skill would be required for the pilot to intercept the descending capsule and guide the pick-up line to the drogue parachute. The problems of poor visibility may be overcome with the use of suitable electronic aids.

As presently configured, the capsule drogue chute opens at 68,000 feet altitude, the main chute opens at 10,000 feet about 2.4 minutes later, and impact in the sea occurs about 5.3 minutes after that, a 7.7 minute period from drogue chute opening to impact. Assuming that the first precise indication of impact location is obtained when the drogue chute opens, the time available for performing an air-to-air snatch would be only about seven and one-half minutes. In that length of time, a 300 knot cruising speed aircraft such as the C-130 could travel 37 nautical miles. Giving each aircraft a radius coverage of 37 nautical miles, the numbers required to cover each high probability area considered in this study would be:

	Area	Number
	1	12
	2,6,7	26
	3	3
	4	3
	5	3
	8	18
Total =		65 aircraft

The total of 65 aircraft is a large number. The number might be reduced by increasing the time available, through an earlier main chute opening or through an increase in main chute size, for example. If the time available can be

doubled to 15 minutes, giving a radius coverage of 74 nautical miles, the total could be reduced to about 25; a further doubling to 30 minutes, 148 n. miles radius, would yield a total of about 13. Each of the numbers quoted here was obtained from Figure 48; Areas 6 and 7 were assumed to be covered by redeployment of aircraft from their initial positions in Area 2. It should be noted that the numbers derived above are optimistically low in that no allowances were included for such items as the reaction time necessary between obtaining the actual descent location and acting on that information, for maneuvering for correct direction of travel to the proper location, for acceleration back to cruise speed after said maneuver, for the presumably necessary reduction in airspeed during the approach prior to snatch, or for making a second pass if the first one misses, etc.

Water-To-Air Retrieve

If an air-to-air snatch is not taken as the guiding rule for deployment, smaller numbers of aircraft could be employed. The aircraft may be deployed in accordance with factors affecting detection and search, considering both line of sight as it varies with altitude, active radar range, and radar or radio beacon reception range. To take an example, referring to Figure 7, a 212 n.mile radius circle on the sea surface could be covered for beacon detection by an aircraft such as the C-130 on station at 30,000 feet, a reasonable altitude for gross weights prevailing at an early point in a flight. The 212 nautical mile value, while beyond active radar range capabilities of current airborne equipment, is within the intended capabilities of equipment currently under development, so that chaff detection would also be possible. At 300 knots cruising speed, the 212 n. mile distance could be traversed in about 43 minutes, so that an access time in the neighborhood of one hour should be within achievement. The vehicle requirement at 212 n. mile radius coverage would be:

Area	Number
1	1
2,6,7	4
3	1
4	1
5	1
8	1
Total =	9

The total of 9 aircraft is noticeably less than the totals given above for an air-to-air snatch. As compared to the preferred retrieve and detection and search vehicle deployments discussed previously, it is 9 aircraft in place of 9 aircraft plus 3 helicopters plus 4 airships plus 8 ships, or 9 total vs. 24 total, a two-thirds reduction in numbers of vehicles required. Also, the access time would average less than one hour as against up to six hours. The advantages of a fixed wing aircraft water-to-air retrieve system are sufficient to indicate the desirability of pursuing that line of development.

Water-to-air retrieve has been developed by the All American Engineering Company. One system utilizes the same retrieving gear and the same aircraft as for the air-to-air system except that the pick-up is from the ground or water. The scheme is to equip the capsule with a telescoping boom or other elevating device to suspend a hook at least 10 feet above its top. Figure 18 shows how this pick-up can be made from a low flying C-130 airplane. The approach and intercept is at a constant low level altitude. Another scheme provides for the aircraft to carry a hook which engages a line extending from the capsule to a float in the water. Figure 17.

Water-to-air pick-up has been successfully accomplished for objects weighing up to 800 pounds. Since the same aircraft and the same sort of retrieving gear are utilized for this pick-up as for the air-to-air pick-up, essentially the same engineering and development program would apply to both.

Disadvantages of this recovery system are the need to incorporate devices for elevating a hook on the capsule and problems of poor visibility. All American Engineering Company has tested a system which uses a water-sensitive material to generate the gas required to extend the telescoping mast. Electronic aids should make poor visibility pick-ups easier to accomplish than in the air-to-air recovery. At night, searchlights on the aircraft would be practical and desirable. In winds of 16 knots or more, the capsule will pitch and roll considerably and probably result in several missed interceptions before pick-up is effected unless suitable stabilization of the capsule can be obtained.

Another type of water-to-air retrieve is the use of a long line attached to an airplane circling overhead. This type of operation is shown in Figure 17. Up to the present time, it has been used to suspend underwater listening devices from the orbiting airplane and the weights of these devices have been in the order of only a few hundred pounds. As far as is known, no actual retrieve of an object the size of the Mercury capsule has been made by this method, but those who are using it believe that pick-up of the capsule could be accomplished provided a suitable aircraft and gear are available. The capsule would then either be winched into the airplane or it could be carried on the end of the line to a ship where it can be redeposited in the water for subsequent pick-up by a ship. Pick-up should be gradual, and load factors on the capsule and suspension gear would be much less than in the snatch technique. One of the foremost problems is one of visibility. The line containing the hook or grappling device to attach to the capsule must be over 1000 feet long and the aircraft must circle so that the hook is in the center of the orbit and close enough to the capsule to enable its attachment either manually or by engagement with a retrieving line shown in Figure 17. At this altitude the capsule will be difficult to see, even under ideal weather conditions, but at night or in haze or wind blown spray, it will be impossible. However, electronic aids may assist the visual control of the operation. It is believed that an engineering study and analysis of the present utilization of this long line technique having as the end result the recovery of the Mercury capsule would show whether such a retrieving means is possible and practical.

Although the above discussion revolves about the assumption of using C-130's, similar figures can also be developed for other aircraft such as the higher speed piston-engine commercial transports: e.g., DC-7 and DC-7C, Super Constellation, etc. These types would tend to show competitive or slightly higher speeds than the C-130 when operating at their higher cruise altitudes, but would be limited at cruising fuel mixtures to about 20,000 feet altitude. As a result, given the requisite radar equipment capabilities, deployment for line of sight coverage of the water surface for beacon detection and active chaff detection at the same range would be in 173 n. mile radius circles, reading from Figure 48 , and the total requirement would be 10 aircraft vs. the 9 mentioned above for the C-130. It should be noted that this discussion does not include the question of aircraft modifications which might be necessary. It is recommended that any development program be set up to include the evaluation of several types of aircraft for relative suitability and desirability, both mission-wise and cost-wise, including the question of aircraft modifications necessary, as well as development of the relative technique.

Large Seaplanes

Many of the advantages of the water-to-air retrieval system would also characterize a recovery system based on the use of the large seaplane capable of taking the capsule aboard, such as the JRM and the R3Y. While not currently operational in the services, both of these type aircraft are in existence. They would doubtless require some modification and reconditioning to prepare them for the Mercury recovery, but no major development program would be needed to prove out their retrieval capabilities.

The principal advantages of the use of large seaplanes include:

1. Equipped with suitable electronics equipment, the large seaplane can function both as a search and retrieval vehicle.

2. Comparatively few vehicles will be required, although more than higher-speed water-to-air snatch airplanes for a given access time.

3. Little or no special modification of the capsule itself will be required to adapt it to the retrieving devices which may be used.

The primary limitation of large seaplanes is their sea state capability. Inasmuch as weather conditions are generally consistent throughout the contemplated high-probability areas - with the exception of the Canary Islands area - this may not be disqualifying, however. The economy of operation they promise certainly merits further evaluation of their sea-state limitations and their possible availability to NASA.

SURFACE SHIPS

We have seen in the case of fixed wing aircraft that future reductions in vehicles, cost and access time required for recovery can come from a development of techniques which permit the high speed detection and search aircraft also to retrieve the capsule.

Present surface ships, while they already have good retrieve capability, lack speed. An example is given in this section, then, to show the improvements in recovery that would result from the use of surface ships having operational speeds of 80 instead of the normally assumed 25 knots. Although this speed is not now attainable with ships capable of participating in the Mercury program, current progress in the development of hydrofoil planing devices and air cushion machines indicates that the time when such vehicles will be available is not far away.

The deployment arrangement assumes:

1. High speed ships having 80 knots operational speed and radar range capability of at least 120 n. mi. against chaff, the horizon would be limiting for active detection of the chaff at 8,000 feet.

2. Search aircraft with the performance characteristics of the C-130 may have radar range capability of at least 200 n. mi. against chaff; this is beyond capabilities of currently operated airborne radar equipment, but is within the capability of equipment under current development.

The resulting arrangement, based on chaff detection, search by aircraft, and retrieve by high speed ships, includes:

1. Land radar detection coverage as shown in Figure 56.

2. Search aircraft at Patrick AFB and Las Palmas in the Canary Islands.

3. Detection plus retrieve high speed ships east of the Cape Canaveral and Bermuda radar coverages, at the eastern end of Area 2, and in Area 4.

4. Retrieve high speed ships in Areas 5 and 8.

5. Detection plus search aircraft between the first high speed ship and the Bermuda radar coverage, between the second and third high speed ship at the eastern end of Area 3 (to cover Area 3 and the distance between Areas 3 and 4), and in Area 8 to cover the area lying outside of land-based coverage.

The total number of vehicles is 6 high speed ships, 4 aircraft for detection and search, and 2 aircraft for search only; the two search-only aircraft need not have the airplane performance and radar range capabilities stipulated above, but rather, could be relatively modest capability types such as the S2F, for example. With this arrangement, access times vary up to about $2\frac{1}{2}$ hours in areas for which 3 hours has been suggested, and up to about $5\frac{1}{2}$ hours where 6 hours has been suggested.

This composite 12-vehicle system may be contrasted with the 24-vehicle ship-aircraft-airship-helicopter system derived in the earlier vehicle deployment section.

V APPENDICIES

A. DETAILED COST SUMMARY

The principal costs of the Project Mercury recovery operation are due to staging the vehicles required and recycling them to their stations, as required, until the project is completed. These costs are summarized for the vehicles of primary interest in Tables 33 through 36 of this appendix and Tables 31 and 32 in the Section "Operational Effectiveness".

Retrieving Vehicles. The retrieving vehicles of interest include:

1. Land-based helicopter. In all cases, the land-based helicopters are assumed to be on ground standby during the alert period. The cost of the one or two helicopters which may actually be dispatched for the retrieval is insignificant compared to the staging costs and is not shown.

2. Airship (ZP). Airships are assumed to be airborne on station during alert periods except for those which may be used in the final recovery area (Area 8).

3. Surface Ships (DD, DER, ATA). The destroyer (DD), radar picket escort vessel (DER), and auxiliary ocean tug (ATA) are taken as typical examples of the 25-knot, 15-knot, and 8-knot surface ships, respectively. Surface ships are assumed to be at sea, on station, during the alert period. It is assumed that they remain at sea in the vicinity of their station from day to day in the event of firing postponements,and that the entire cost of their operation during this time is charged to the recovery program.

4. Aircraft Carrier (CVS). The aircraft carrier is assumed to be maintaining three stations during the recovery operation: one helicopter retrieval station and two aircraft detection stations with the aircraft on deck standby. (Although more than 2 aircraft may be used to advantage for continuous chaff coverage, a maximum of 2 stations can be maintained at the increased spacing which occurs when travel time is permitted the detection aircraft.) The operating cost of the CVS is therefore divided by three to compare its cost with other vehicles capable of maintaining only one station. If it is unable to maintain these three stations because of range limitations, its operating cost is, of course, higher.

5. Ship-based helicopter (LSD+HS). The cost of the ship-based helicopter (aside from those based on aircraft carriers) is assumed to be the operating cost of the typical ship suitable for sea-going helicopter operations, the Dock Landing Ship (LSD).

Detection Vehicles. The aircraft suitable for detection which are evaluated are the S2F, SA-16 (UF), P2V, P5M, and WV-2. In determining the cost of the operation, detection aircraft are assumed to be on ground standby during delays wherever this is possible. The WF-2 cost is assumed comparable to that for the S2F.

Number of Vehicles Required. The total cost is determined for three of the complexes described in the section "Vehicle Deployment": those for complete surface detection coverage, for complete chaff detection coverage, and for minimum cost. The numbers of vehicle stations and the types of vehicles are summarized in Table 36.

In order to allow for less than 100% availability of the aircraft which may be required for day-in day-out use with postponements, additional aircraft must be assigned to the operation. Figure 28 shows the number of aircraft which must be on hand to assure a specific number of available aircraft, based on a sample period of time in 1956 and the availability of aircraft for their normally assigned mission. The normal missions of the Anti-Submarine Warfare and Aircraft Early Warning aircraft among those shown may require that a great deal of complex electronic equipment be operating: more than that required for the Mercury search. Also, all of these aircraft models will have been in service for a longer period of time when the Mercury recovery occurs and presumably will have increased availability as a result of greater service experience with them.

On this basis, the availability of all of the aircraft models of interest will be assumed to be at least 75%. Figure 28 indicates that doubling the number of aircraft assigned to the operation assures an availability of over 93% under these circumstances. It will be desirable to over-assign aircraft rather than risk delays in the firing due to unavailable aircraft, inasmuch as aircraft on standby are relatively cheap while ships at sea are relatively expensive.

Where appropriate, the staging cost of the additional vehicles - determined from Tables 33 and 34 - are added to the summary of unit costs in Table 35 to determine total cost of the operation. The cost of staging the standby airplanes is included in the total cost described below.

Total Cost. Total cost is determined for two conditions:

1. Minimum mission, in which the vehicles are assumed to proceed to their staging bases, from there to their stations, remain on station for two hours, return to staging base, and return home.

2. Mission including 10 daily postponements, in which the vehicles are assumed to be recycled to their stations on each of ten successive days, maintaining station for two hours each day. Surface ships are assumed to be at sea, charging their cost to the recovery program during the entire time.

These costs are itemized in Tables 31 and 32 in "Operational Effectiveness". The total cost as a function of the number of daily postponements is shown there in Figure 59.

Total Cost in Vehicle-Days. In addition to the cost in dollars as described earlier, the total cost of the recovery operation may be measured by the number of vehicles committed and the number of days they are required. The number of days required includes the time needed for staging, as well as the time required for the operation. The number of vehicles includes standby aircraft as described above.

The required staging time is rounded to the next larger integral number of days. For aircraft, it is assumed that the minimum mission includes a full day's operation from the staging base with departure for home delayed until the following day. The number of days required includes consideration of overnight stops. Ships are assumed to head home immediately following their two hours on station for the minimum mission; hours underway are assumed to be consecutive and the number of days required for the mission is obtained by rounding to the next number of integral days larger than the consecutive hours underway.

For helicopters based at Bermuda and the Canary Islands, airlift from the U.S. by a C-124 is assumed. The airlift airplane is assumed to remain at the base during the recovery operation so that two vehicles are committed to the operation for each land-based helicopter station outside the continental United States.

TABLE 33

RETRIEVING VEHICLE DETAILED COSTS
(MILES & THOUSANDS OF DOLLARS)

Vehicles	Cost Mile	1	2(West) & 7	2(Bermuda) & 6	2(East)	3	4	5	8		
Miles To Staging Base (One Way)											
HS Land-Based Helicopter		0	-	640	-	-	-	2890	960		
ZP Airship		180	640	640	640	-	-	2890	1260		
Surface Ships		0	0	0	0	0	0	0	0		
Miles From Staging Base To Station (One Way)											
HS Land-Based Helicopter		0	-	0	-	-	-	0	0		
ZP Airship		150	250	0	250	-	-	60	150		
Surface Ships		455	455	640	1350	1840	2200	3200	720		
Cost Per Vehicle In Transit To & From Staging Base											
HS Land-Based Helicopter	$ .75 (a)	$ 0	-	$ 1.0	$ -	-	-	$ 4.3	$ 1.4		
ZP Airship	9.30	3.3	$ 11.9	11.9	11.9	-	-	53.8	23.4		
Surface Ships		0	0	0	0	$ 0	$ 0	0	0		
Cost Per Vehicle In Transit Between Staging Base & Station → And For →										2 Hours on Station	22 Hours Delay
HS Land-Based Helicopter	-	$ 0	$ -	$ 0	$ -	$ -	$ -	$ 0	$ 0	$ 0	$ 0
ZP Airship	$ 9.30	2.8	4.6	0	4.6	-	-	1.1	0 (b)	.7 (c)	0
DD Destroyer	31.50	28.7	28.7	40.3	85.0	115.9	138.6	201.6	45.4	.9	9.8
CVS Aircraft Carrier (3 Stations)	56.70	51.6	51.6	72.6	153.1	208.7	249.5	362.9	81.6	1.6	17.6
DER Radar Picket Escort Vessel	29.10	26.5	26.5	37.2	78.6	107.1	128.0	186.2	41.9	.6	6.1
ATA Auxiliary Ocean Tug	14.50	13.2	13.2	18.6	39.2	53.4	63.8	92.8	20.9	.3	3.2
LSD +HS Ship-Based Helicopter	55.70	50.7	50.7	71.3	150.4	205.0	245.1	356.5	80.2	1.3	14.0

(a) Assumed Airlifted By C-124
(b) Assumed To Stand By On Ground
(c) Zero, For Ground Standby

TABLE 34

DETECTION VEHICLE DETAILED COSTS

(MILES & DOLLARS)

Unit Cost			Detection Stations 1	2	Bermuda Ground Base	3	4	5	6	7	7a(Area 3)	7b(Area 4)	8	9	10
		CONUS to Base-Round Trip Miles	0	0	1280	1280	1280	1280	1280	4060	4060	4060	5780	1580	2440
		Base to Station-Round Trip Miles	0	840	0	280	240	880	1500	1220	1560	1000	0	0	0
$1.196/Mi. 161.16/Hr.	SA-16	Between CONUS and Base	$0	$ 0	$0 (a)	$ 0 (a)	$ 0 (a)	$ 0 (a)		$4856	$4856	$4856	$6913	$1890	$2918
		Between Base & Station	0	1005	0	335	287	1052		1459	1866	1196	0	0	0
		2 Hours on Station	322*	322	0*	322	322	322		322	322	322	0*	0*	0*
		Total-Minimum Mission	322*	1327	0*	657	609	1374		6637	7044	6374	6913	1890	2918
		Total-10 Daily Recycles	3220*	13270	0*	6570	6090	13740		22666	26736	20036	6913	1890	2918
$1.278/Mi. 217.00/Hr.	P2V	Between CONUS & Base	0	0	1636	1636	1636	1636	$1636	5189	5189	5189	8835	2415	3118
		Between Base & Station	0	1074	0	358	307	1125	1917	1559	1994	1278	0	0	0
		2 Hours on Station	434*	434	0*	434	434	434	434	434	434	434	0*	0*	0*
		Total-Minimum Mission	434*	1508	1636*	2428	2377	3195	3987	7182	7617	6901	8835	2415	3118
		Total-10 Daily Recycles	4340*	15080	1636*	9556	9046	17226	25146	25119	29469	22309	8835	2415	3118
$2.140/Mi. 460.46/Hr.	WV-2 (Full Crew)	Between CONUS and Base	0	0	2739	2739	2739	2739	2739	8688	8688	8688	12369	3381	5222
		Between Base & Station	0	1798	0	599	514	1883	3210	2611	3338	2140	0	0	0
		2 Hours on Station	921*	921	0*	921	921	921	921	921	921	921	0*	0*	0*
		Total-Minimum Mission	921*	2719	2739*	4259	4174	5543	6870	12220	12947	11749	12369	3381	5222
		Total-10 Daily Recycles	9210*	27190	2739*	17939	17089	30779	44049	44008	51278	39298	12369	3381	5222
$1.710/Mi. 256.45/Hr.	P5M	Between CONUS & Base	0	0	0 (a)	0 (a)	0 (a)	0 (a)	0 (a)	6943	6943	6943	9884	2702	4172
		Between Base & Station	0	1436	0	479	410	1505	2565	2086	2668	1710	0	0	0
		2 Hours on Station	513*	513	0*	513	513	513	513	513	513	513	0*	0*	0*
		Total-Minimum Mission	513*	1949	0*	992	923	2018	3078	9542	10124	9166	9884	2702	4172
		Total-10 Daily Recycles	5130*	19490	0*	9920	9230	20180	30780	32933	38753	29173	9884	2702	4172
$1.000/Mi. 129.89/Hr.	S2F (Land Based)	Between CONUS and Base	0		1280	1280	1280						5780	1580	2440
		Between Base & Station	0		0	280**	240**						0	0	0
		2 Hours on Station	260*		0*	260	260						0*	0*	0*
		Total-Minimum Mission	260*		1280*	1820	1780						5780	1580	2440
		Total-10 Daily Recycles	2600*		1280*	6680	6280						5780	1580	2440

(a) Use existing airplanes based on Bermuda
** Will need relief on station if impact occurs in area.
* Zero, for standby on ground.

Restriction/
Classification
Cancelled

TABLE 35

SUMMARY OF UNIT COSTS
(THOUSANDS OF DOLLARS)

MINIMUM MISSION (2 Hours on Station)

Retrieving Vehicles/Area	1	2(West) & 7	2(Bermuda)& 6	2 (East)	3	4	5	8	Overshoot
HS	$ 0	-	$ 1.0	-	-	-	$ 4.3	$ 1.4	
ZP	6.9	$ 17.3	12.6	$ 17.3	-	-	55.6	23.4	
DD	29.6	29.6	41.2	85.9	116.8	139.5	202.5	46.3	
*CVS (1 Retrieve + 2 Detection Stations)	53.2	53.2	74.2	154.7	210.3	251.1	364.5	83.2	
DER	27.0	27.0	37.8	79.1	107.6	128.6	186.8	42.5	
ATA	13.5	13.5	18.9	39.4	53.7	64.1	93.1	21.2	
LSD + HS	52.0	52.0	72.5	151.7	206.2	246.3	357.8	81.5	

Detection Vehicles/ Station	1	2	Bermuda Ground Base	3	4	5	6	7	8	9	10
S2F (Land-Based)	0	-	1.3	1.8	1.8	-	-	-	5.8	1.6	-
SA-16	0	1.3	0	.7	.6	1.4	-	6.6	6.9	1.9	2.9
P2V	0	1.5	1.6	2.4	2.4	3.2	4.0	7.2	8.8	2.4	3.1
P5M	0	1.9	0	1.0	.9	2.0	3.1	9.5	9.9	2.7	4.2
WV-2 (Full Crew)	0	2.7	2.7	4.3	4.2	5.5	6.9	12.2	12.4	3.4	3.4

MISSION INCLUDING 10 DAILY HOLDS

Retrieving Vehicles/Area	1	2(West) & 7	2(Bermuda)&6	2 (East)	3	4	5	8	Overshoot
HS	$ 0	-	$ 1.0	-	-	-	$ 4.3	$ 1.4	
ZP	38.7	65.8	19.3	$ 65.8	-	-	72.4	23.4	
DD	135.9	135.9	147.6	192.3	$ 223.2	$245.9	308.9	152.6	
CVS (1 Retrieve + 2 Detection Stations)	243.6	243.6	264.6	345.1	400.7	441.5	554.9	273.6	
DER	93.4	93.4	104.2	145.5	174.0	195.0	253.2	108.9	
ATA	48.2	48.2	53.6	74.2	88.4	98.8	127.8	55.9	
LSD + HS	203.1	203.1	223.7	302.8	357.4	397.5	508.9	232.6	

Detection Vehicles/ Station	1	2	Bermuda Ground Base	3	4	5	6	7	8	9	10
S2F (Land-Based)	0	-	1.3	6.7	6.3	-	-	-	5.8	1.6	-
SA-16	0	13.3	0	6.6	6.1	13.7	-	22.7	6.9	1.9	2.9
P2V	0	15.1	1.6	9.6	9.0	17.2	25.1	25.1	8.8	2.4	3.1
P5M	0	19.5	0	9.9	9.2	20.2	30.8	32.9	9.9	2.7	4.2
WV-2 (Full Crew)	0	27.2	2.7	17.9	17.1	30.8	44.0	44.0	12.3	3.4	3.4

* Does not include cost of staging standby vehicles.

TABLE 36

SUMMARY OF STATION DISPOSITIONS

Reference: Figures 51, 56, 57

Area	1	2(West)&7		2(Bermuda)&6		2(East)	3	4	5	8	Overshoot
Retrieving Vehicles (All 3 Complexes)											
Helicopter (HS)	1*			1*					1*		
Airship (ZP)		1				1				2*	
Destroyer (DD)	1	1				2	1	1			
Station	1	2	Bermuda Ground Base	3	4	5	6	7	8	9	10
Detection Vehicles (Minimum Cost Complex)											
S2F									1*	1*	
SA-16 (UF)	1*		1*					1			
P5M							1				
(Complete Chaff Detection Complex)											
S2F	1*								1*	1*	
SA-16 (UF)		1		1	1			1			1*
P5M						1	1				
Station	1	2		4	5	7	8, 9	10, 11	12	13, 14	15-17
(Complete Surface Detection Complex)											
WV-2		1					1				
P5M				1	1	1	1				
P2V	1							(Area 3) 1 (Area 4) 1	1	2*	3*

* On Ground Standby For Minimum Cost

B. REFERENCES

During the course of this study, data from the following reports, papers, and charts have been used:

1) Map of the West Indies, National Geographic Society, March 1954.

2) Map of the World, National Geographic Society, March 1957.

3) Map of the Atlantic Ocean, National Geographic Society, December 1955.

4) World Aeronautical Charts, USAF Aeronautical Chart and Information Center, Air Photographic and Charting Service, (WATS).

5) Aeronautical Planning Charts, USAF Aeronautical Chart and Information Center.

6) H.O. 1400, Pilot Charts of the North Atlantic Ocean, U.S. Navy Hydrographic Office.

7) North Atlantic Bathymetric Charts, U.S. Navy Hydrographic Office (Confidential).

8) H.O. Pub. No. 306, U.S. Navy and U.S. Air Force Seaplane Pilot's Handbook, North Atlantic, U.S. Navy Hydrographic Office.

9) H.O. Pub. No. 308, U.S. Navy and U.S. Air Force Seaplane Pilot's Handbook, Caribbean, U.S. Navy Hydrographic Office.

10) H.O. Pub. No. 310, U.S. Navy and U.S. Air Force Seaplane Pilot's Handbook, Africa, U.S. Navy Hydrographic Office.

11) International Flight Information Manual, Volume 8, General Services Office, Civil Aeronautics Administration, February 1958.

12) NAVAER 50-1C-528, U.S. Navy Marine Climatic Atlas of the World. Volume 1, North Atlantic Ocean, U.S. Government Printing Office, November 1, 1955.

13) Report 1091, Statistics on Wave Heights and Periods for the North Atlantic Ocean, David Taylor Model Basin, September 1957. (Confidential).

14) NADC-WR-510, Oceanographic Factors of Major Importance in Submarine Detection, Air Warfare Research Department, U.S. Naval Air Development Center, June 1957. (Confidential).

15) DR Report No. 1331, Brief Summary of Wind Speed, Wind Wave and Swell Data at Selected Points on the Earth's Surface, U.S. Navy Bureau of Aeronautics, July 1951. (Confidential).

16) U.S. Navy Hydrographic Office, Unpublished Data on Probability of Wave Heights in the North Atlantic Ocean.

17) U.S. Navy Hydrographic Office, Unpublished Data on the Characteristics of the Sofar Channel Surrounding Bermuda. (Confidential).

18) National Search and Rescue Manual, The President's Air Coordinating Committee, October 1958.

19) NWP 37, Search and Rescue, U.S. Navy Chief of Naval Operations, January 1953.

20) WADC TR 54-160, Chapter 7, Visual Detection and Identification.

21) Jane's All the World's Aircraft, 1958-1959, McGraw-Hill.

22) Jane's Fighting Ships, 1958-1959, McGraw-Hill.

23) Fahey's The Ships and Aircraft of the U.S. Fleet, Seventh Edition, Ships and Aircraft, October 1958.

24) Introduction to the Theory of Statistics, by A. McF. Mood, McGraw-Hill, 1950.

25) NASA Space Task Group, Recovery Operations for Project Mercury, March 20, 1959.

26) NASA Langley Research Center, Specification No. S-45, Specifications for Tracking and Ground Instrumentation Systems for Project Mercury, May 21, 1959.

27) McDonnell Aircraft Corporation Report No. 6821, Project Mercury Indoctrination, Revised 21 May 1959.

28) Investigation of Electronic Equipment Reliability as Affected by Electron Tubes. Interbase Report No. 1. A Preliminary Study of Electronic Equipment Reliability and Reliability Prediction. ARINC Publication No. 60, March 15, 1955.

29) Effect of Heater-Voltage Modification on Reliability of AN/ARC-27 Receiver Transmitter. ARINC Publication No. 77, November 4, 1955.

30) S. R. Scott: Techniques of System Reliability Measurement, Vol. 2, Publication No. 101-6-129, December 12, 1958.

31) R. C. Horne: Reliability of the AN/APS-20 System. Publication No. 101-11-139, May 15, 1959.

32) S. R. Scott: Determination of Base Spare-Unit Requirements for AN/ARC-34 Equipment. Publication No. 123, August 15, 1958.

33) IRE, Fifth National Symposium on Reliability and Quality Control in Electronic Proceedings. R. L. VanderHorne: AN/ARC-58 Reliability Program Case History. January 1959.

34) Goodyear Aircraft Corp. GR-8438: An Operational Evaluation of Airship Early Warning Squadron One (ZW-1) 12/2/57 (Confidential).

35) Analysis of Operator-Equipment Relationships, ARINC Publication No. 101-7-131, December 19, 1958.

36) Evaluation of Incoming-Inspection and Selection Procedures for Electron Tubes. ARINC Publication No. 117, April 4, 1958.

37) OPNAV Flight Activity of Naval Aircraft, July 1956.

38) Naval Aviation News, page 16, March 1959.

39) Techniques for Reliability Measurement and Prediction Based on Field Failure Data, Vitro Laboratories Technical Report No. 80, 10 October 1955.

40) Reliability Prediction and Measurement of Shipboard Electronic Equipment, Vitro Laboratories Technical Report No. 97, 15 April 1957.

41) U.S. Navy Aircraft Accident Statistics for Fiscal 1958, U.S. Naval Aviation Safety Center. (Confidential).

42) Republic Aviation Corp., letter of July 15, 1959.

43) Yearly Review of Progress. ARINC Publication No. 116, 1 April 1958.

44) Maintainability of the AN/WRT-2 Transmitter, ARINC Publication No. 120, 23 May 1958.

45) Evaluation of Electronic Equipment Reliability by Laboratory Measurement, Vitro Laboratories Technical Report No. 111, 30 January 1959.

46) Tabulation of MTBF data on Shipborne Electronic Equipment obtained from T.F. Krivak, Bureau of Ships, Code 695B.

47) Department of the Air Force AFM 26-1, "Manpower Policy and Criteria, Addendum 1", December 1956.

48) Department of Defense Appropriations for 1960, Hearings before the Subcommittee of the Committee on Appropriations, House of Representatives, 86th Congress, 1st Session, U.S. Government Printing Office, Washington: 1959.

49) Cost Estimates for Operating Ships, Aircraft, and Task Forces, Fiscal Year 1959, NAVEXOS P-1903, Office of the Comptroller, Department of the Navy, 15 April 1958, (Confidential).

50) Summary of Fuel Used and Hours Underway for the Period October 1955 through December 1957, Data prepared by R. Landers, Code 373, Office of the Chief of Naval Operations, Undated, (Confidential).

51) The Earnings and Employment of Seamen on U.S. Flag Ships, Bulletin No. 1238, U.S. Department of Labor, Bureau of Labor Statistics, November 1958, U.S. Government Printing Office, Washington.

52) Revised Schedule of Wages for Civilian Marine Personnel, MSTS 26 and 126, amended to 29 May 1959, Military Sea Transportation Service, Department of the Navy, Washington: 1959.

53) Department of Defense Appropriations for 1959, Department of the Navy Hearings before the Subcommittee of the Committee on Appropriations, House of Representatives, 85th Congress, 2nd Session, U.S. Government Printing Office; Washington: 1958.

54) W. M. Hall, "Pulse Radar Performance", Proc. IRE, Vol. 44, pp. 224-231, February 1956.

55) McDonnell Aircraft Corp. Memo No. EE-974, dated 17 July 1959, "Tracking Range of the Project Mercury Capsule using the SCR-584 Mod II (by Reeves) and the AN/FPS-16 Radars".

56) "ASW Aircraft Equipment and Capabilities", ASW Tactical School, Norfolk, Virginia (Confidential).

57) "Development of Air and Coordinated Air-Surface Tactics for Use Against Medium-Speed Deep-Diving Submarines", Seventh Partial Report on Project OP/V32/A16-3(17) (Revised), Commander Operational Development Force, U.S. Navy, July 1949, (Confidential).

58) International Telephone & Telegraph Corp., "Reference Data for Radio Engineers", Fourth Edition, 1956, New York.

59) GAEC Memo, "Visit to McDonnell Aircraft, St. Louis, Regarding Capsule Characteristics for Mercury Recovery Study (24 June 1959)", from R. A. Houghton and R. L. McConaughy.

60) GAEC Memo, "Mercury Recovery (Project 226A - Visit to (A) NASA, Langley Field, Virginia, June 4, (B) Destroyer Flotilla 4, Norfolk, Virginia, June 5, (C) CINC LANT FLT, Norfolk, Virginia, June 5, Concerning", H. Beers, et al, 24 June 1959.

61) GAEC Memo "Visit to BuShips and BuAer regarding communications and homing for Mercury, Project 226A, July 24, 1959", R. L. McConaughy, July 27, 1959.

62) Avionics Installation Plan (for specific aircraft), Enclosure (2) of BuAer Letter AER-AV-4438, (Confidential).

63) "Basic Fleet Operational Communication Doctrine", NWP 16, Dept. of the Navy, Office of the Chief of Naval Operations, September 1953 (Confidential). This volume refers to other Navy Dept. publications (Ref. 64 - 66) for support and amplification.

64) "Employment of Communications", NWIP, 16-1

65) "U.S. Naval Communications Instructions", DNC-5.

66) "Recommended Frequency Bands and Frequency Guide", DNC-14.

67) "LORAN Accuracy Diagram",H.O. Misc. 15308, 3rd Edition October 1954, U.S. Navy Hydrographic Office. (The N.Y. branch of the Hydrographic Office indicates this diagram is current).

68) Military Specification "Receiving Set, Countermeasures, AN/ALR-3", MIL-R-18020A (Aer), 15 July 1955, (Confidential).

69) Military Specification, "Receiving Set, Radar, AN/ALR-5", MIL-R-25163 (USAF), 27 April 1955.

70) GAEC, "Avionics Equipment Utilization Chart", (Confidential).

71) GAEC Memo, "Visit to Air Rescue Service, Orlando, Florida, May 22, 1959, Regarding Mercury Recovery Project 226A, R. A. Houghton and R. L.McConaughy, June 10, 1959.

72) "Avionics Bench, Pre-Flight and Flight Test Instructions for Receiving Set, Countermeasures AN/ALR-8", ET-201A, Dept. of the Navy, Bureau of Aeronautics, 1 June 1957, (Confidential).

73) "Handbook Service Instructions, Countermeasures Receiving Set AN/ALR-8", NAVAER 16-30ALR8-502, Navy Bureau of Aeronautics, (Confidential).

74) "ECM Antennas for Today and Tomorrow", U.S. Naval Aviation Electronics Digest, June 1955, (Confidential). See also MIL-D-5025A (Aer), 15 January 1951, on "Direction Finder Group AN/APA-69 and AN/APA-69A"(Confidential).

75) "Report on the Performance of the AN/ARA-25 UHF Homing Adapter in Model UF-1 Airplanes", EL-64R2, Grumman Aircraft Engineering Corp., June 1, 1954.

76) "Electronics Demonstration of the F9F-8P Airplane", Report No. 3098.82, Part II, Grumman Aircraft Engineering Corp., Nov. 15, 1956,(Confidential).

77) "Instruction and Maintenance Manual for SARAH (Search and Rescue and Homing) Equipment", Ultra Electric, Ltd.,London, England. See also Simmonds Accessories, Inc. brochure PD 5503 on SARAH.

78) "Atkins Anti-Collision Light or Relative Danger Light", Brochure of the Aircraft Danger Light Corp., 1755 Rand Tower, Minneapolis 2, Minn.

79) Tabulation of Typical Equipments Aboard Several Types of Vessels Obtained from T. F. Kriwak, Bureau of Ships, Code 695 .

80) "List of Nomenclature Assigned to Naval Electronic Equipments", NAV-SHIPS 900123(B), CO-NAVAER 16-45-511, BuShips, Dept. of Navy, January 1956, (Confidential).

81) "Military Specification, Radio Sets AN/ARC-27 and AN/ARC-27A", MIL-R-5068D (Aer), BuAer, Dept. of Navy, 15 May 1957.

82) "Military Specification, Radio Set AN/ARC-38", MIL-R-18173 (Aer), BuAer, Dept. of Navy, 1 September 1954.

83) "Description of the Avionics System Installed in the Grumman Albatross Search and Rescue Aircraft, Grumman Aircraft Engineering Corp., Report AV-64R15.0, 18 November 1958.

84) Bureau of Aeronautics letter Aer-MA-2321/83 of 20 Aug. 1959 to GAEC, Enclosure.

In addition to the preceding material, the following agencies and organizations have been contacted for information and advice. Their generous efforts in helping us gather basic data for this brief study (often on short notice) are greatly appreciated.

Air Force Ballistic Missile Division
Air Rescue Service, USAF, Orlando
All American Engineering Company
Atlantic Missile Range
CINC LANT FLT, Norfolk
Coast Guard Headquarters, Washington
New York District Office, U.S. Coast Guard
Destroyer Flotilla 4, Norfolk
McDonnell Aircraft Corporation
NAS, Lakehurst
NASA, Langley Field
Navy Bureau of Aeronautics
Navy Bureau of Ships
Navy Hydrographic Office
Office of the Chief of Naval Operations
Operations Evaluation Group
Pacific Missile Range
Special Weapons Branch, Office of Chief of Research and Development, Army Chief of Staff
Vertol Aircraft Corporation

C. U.S. Navy Aircraft Cost Data

The direct hourly operating costs used in this study include fuel and oil costs, maintenance labor, and the cost of the flight crew. It is pointed out that this is not a complete statement of the operating cost of an airplane - inasmuch as it does not include the cost of spare parts and other maintenance material - but should be sufficient to provide a valid comparison between aircraft.

Additional data on the cost of operating U.S. Navy aircraft, Reference 84, were received too late to incorporate in the body of this report. This information is shown in Table 37. NSA (Navy Supply Account) cost is understood to include, in addition to fuel and oil, minor maintenance expendables, particularly for electronics equipment. For airships, it includes helium consumed. APA (Appropriation Purchases Account) cost is understood to consist primarily of spare parts for the airframe, engines, and electronic equipment. These additional hourly costs have been added to the cost of maintenance labor and flight crew indicated in Table 20 for the purpose of comparison of these total costs to the direct costs used in the study. Prorated overhaul costs are not included in the comparison. The result is shown in Figure 62.

The principal variation from the data used occurs in the case of the HR2S helicopter where the APA cost is considerably out of proportion to the other operating expenses. Helicopters are considered as potential retrieval vehicles in this study and the economic case for them is based on the fact that they are not required to be airborne during delays in the firing. They are considered to be transported to their stations by cargo aircraft or surface ships. They therefore incur no operational expense of their own, aside from the one or two which might actually be dispatched for the capsule retrieval, an insignificant amount. In spite of the relatively high operating cost of the HR2S helicopter, therefore, the economic case for the use of helicopters as retrieval vehicles, including the HR2S, is not changed.

The operating cost of the ZPG-2, 2W aircraft is also seen to be higher than anticipated with respect to other aircraft. The airship is also conceived primarily as a retrieval vehicle, however, so that its cost relative to ships and other potential retrieval vehicles is the criterion by which it should be judged. Although the cost advantage of airships, with respect to surface ships, may not be as pronounced as indicated in Tables 31 and 32, they would still appear to be less expensive at ranges within the limits of their operational suitability.

There is also a small variation in the cost of the HSS and HUS helicopters, considered to be interchangeable in this study. This occurs primarily as APA expense and is probably due to the additional electronics equipment required for the ASW mission of the HSS. The difference has no relevance to this study.

Although some variation exists between the current operational costs of the Navy aircraft and the costs used in this study, therefore, the differences do not alter the conclusions reached in the report.

Restriction/
Classification
Cancelled

Confidential

TABLE 37

OPERATION AND MAINTENANCE COSTS OF U.S. NAVY AIRCRAFT*
(Per flight hour)

Model	Fuel	Oil	Other NSA	APA	Total Operating Cost	Aircraft Overhaul	Engine Overhaul	Total
HR2S-1	$35.98	$1.91	$ 8.30	$478.79	$524.98	$200.78	$32.38	$758.14
HSS-1,2	14.57	.32	2.21	110.43	127.53	82.87	6.84	217.24
HUS-1,1A	11.37	.44	3.49	73.54	88.84	77.11	6.84	172.79
P2V-6,7	48.55	1.75	9.51	114.20	174.01	85.63	41.20	300.84
P5M-1,2	51.32	1.94	12.09	259.94	325.29	226.01	18.66	569.96
R6D-1	79.39	1.47	10.07	94.22	185.15	31.25	29.12	245.52
R7V-1	87.28	2.35	12.79	230.73	333.15	50.00	44.04	427.19
S2F-1	17.50	.50	3.33	76.54	97.87	43.82	9.34	151.03
UF-1,2	21.28	1.04	6.79	83.82	112.93	123.56	10.96	247.45
WV-2	90.63	2.77	19.38	209.04	321.82	50.00	35.24	407.06
ZPG-2,2W	9.58	.51	55.04	342.49	407.62	267.89	10.82	686.33

*Official Navy cost figures were received subsequent to the completion of this study. A comparison with the values used herein is shown in Figure 62, page C-3.

NSA = Navy Supply Account
APA = Appropriation Purchases Account

See Reference 84

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NAVAL AIRCRAFT OPERATING COSTS

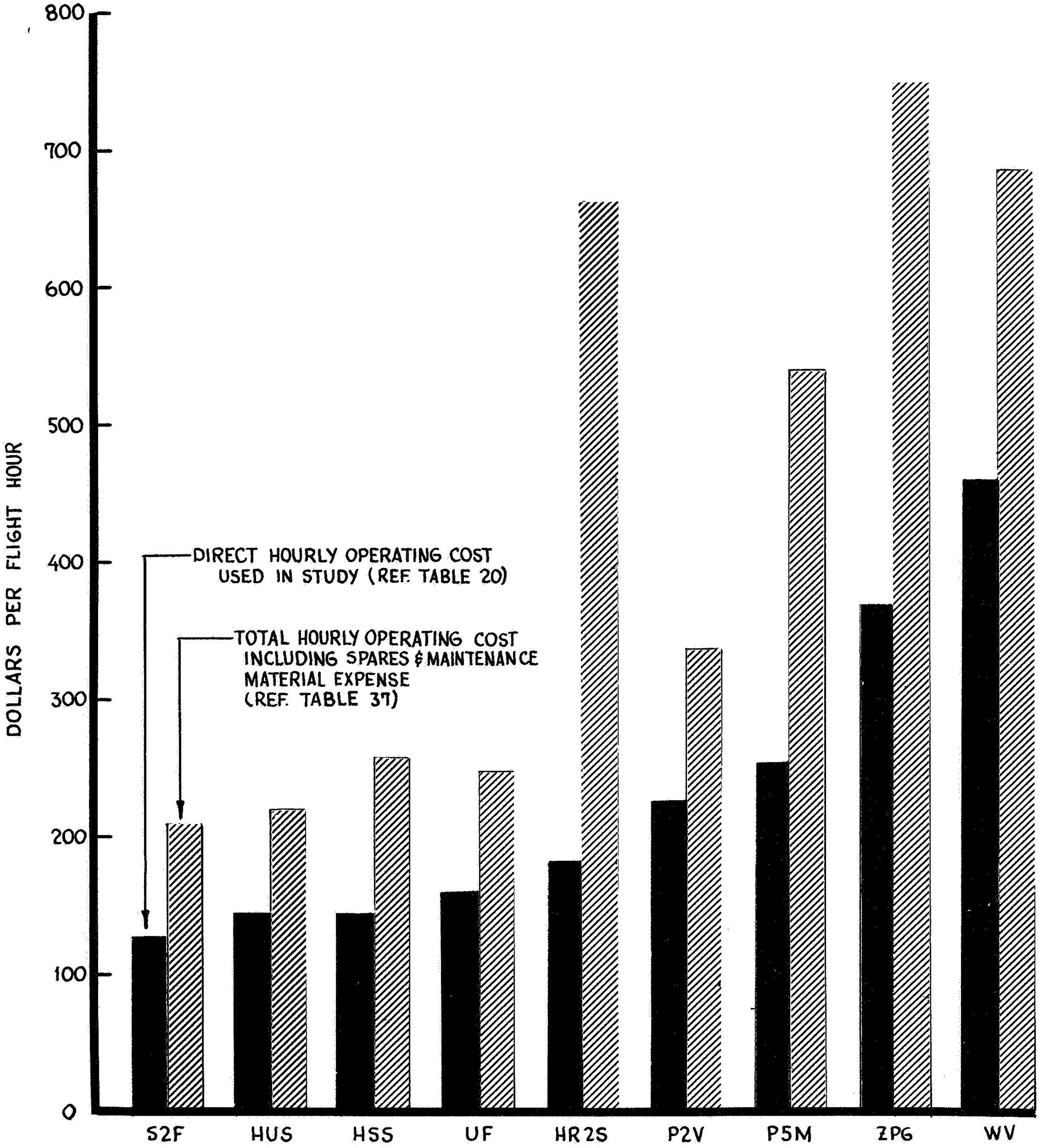

FIG. 62